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Graphitization Symposium—I

The Principles of Graphitization

By H. A. Schwartz*, Cleveland, Ohio

Abstract

Graphitization of white iron from which malleable iron is made is not completely understood. While many factors have been carefully investigated, others have been but superficially studied. In this paper, the author outlines the various factors which must be taken into consideration in the graphitization of white iron to produce malleable iron as known today. For example, he discusses the effect of time, temperature and composition on the structure produced during solidification of cast irons, the effect of temperature on the decomposition of iron carbide, the effect of temperature on graphite precipitation, mechanism of the formation of various structures in malleable iron, and finally summarizes process steps. He then discusses the various factors influencing the number of nodules of temper carbon which may be present in malleable iron, outlining the manner in which nodules are formed, as well as the effect of the number and type of nodules on the physical properties. This paper also deals at considerable length with the difficulties encountered in a study of the graphitizing rate, pointing out the errors possible in chemical analysis, and expansion, electric resistance and metallographic methods, as well as those methods dependent on observation of the first graphite. He also discusses causes for the variations in graphitizing rate and the effect of various alloying elements on that rate. He explains quite completely the film theory of retardation of graphitization. The author next explains the effects of gases and of various atmospheres on graphitization and

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also some effects of melting operations. He ends his paper with a discussion of other graphitizable materials, such as the graphitizable steels, which have brought forth several other factors heretofore not considered in a study of graphitization.

A very complete bibliography is appended to the paper and the author suggests that those who are interested in more complete information of the subject than presented in this paper, use the bibliography for further information.

1. The process of annealing hard iron to convert it into malleable cast iron represents the conversion of a compound of iron and carbon, called cementite, into free carbon (graphite) and iron. Accordingly, the chemical process which underlies the commercial operation is frequently referred to as graphitization.

2. It falls to the present author's lot in this symposium to discuss the principles of this process. In doing so we will avoid as far as possible any attempt at a strictly scientific treatment of the subject and confine ourselves to a general description. Those who may wish to study systematically what has been learned on the subject may read as much of the attached bibliography as they find desirable for their own purposes. Presumably every statement made in the body of this paper will find support or demonstration in some of these earlier publications. Individual references will be avoided in the interest of simplicity.

Effect of Time, Temperature and Composition Solidification Structure

3. Whatever may be the state of the carbon in liquid cast iron, the product would always solidify and cool to a mixture of iron and graphite if the conditions were favorable. This process, however, requires time and very generally the cast irons freeze as mixtures of graphite, iron carbide and iron. If the conditions are made particularly favorable, by a suitable selection of chemical composition and cooling rate, then the metal solidifies and cools as a mixture of iron carbide and iron. The unannealed casting of the malleable industry is in this state. Its microstructure is then that shown in Fig. 1.

4. Liquid cast iron would always freeze with separation of graphite at a higher temperature, and hence, sooner than the sep-

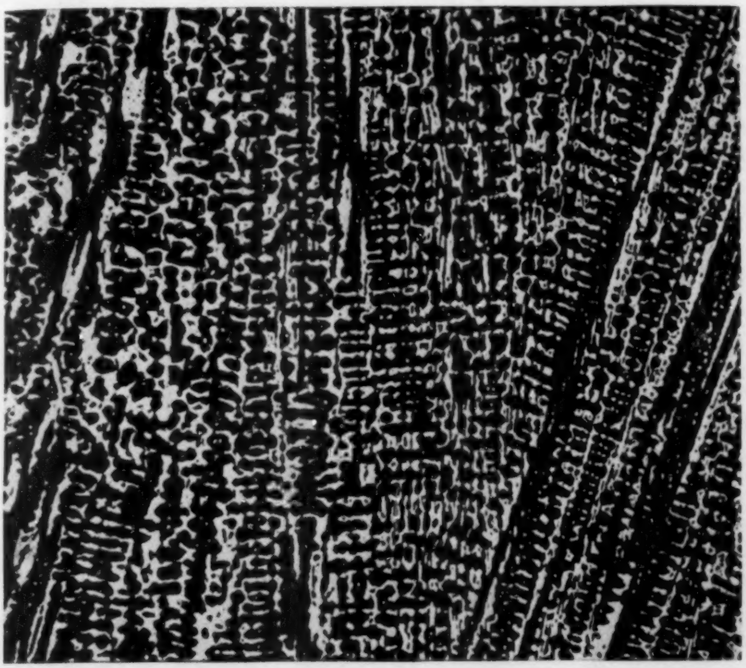

FIG. 1—WHITE CAST IRON. ETCHED WITH NITAL, x100.

aration of iron carbide. Since it takes time, however, for liquid metal to solidify, it may be that heat is taken away by the mold more rapidly than it can be liberated by the freezing of the metal and hence that the metal is "supercooled," *i.e.*, it is made to freeze at temperatures below the normal freezing point. If this supercooling is sufficient, freezing may be entirely in the iron-iron carbide condition, which is desired by the malleable founder.

Effect of Temperature on Iron Carbide Decomposition

5. The iron carbide so produced then will appear to remain unaltered so long as the material is kept at room temperature, even through very great time intervals, running into centuries. The iron carbide, however, is still what the metallurgist calls "metastable." It wishes to transform itself into iron and carbon, even though it finds it is unable to do so under the existing circumstances. The principal retarding influence to its decomposition is the relative immobility of iron and carbon atoms at room temperature. If we raise the temperature, the opportunity for chem-

ical reaction is much increased and the iron carbide proceeds to decompose.

6. It was known even to the father of the industry, Seth Boyden, that this process went on most effectively at rather high temperature, which he compared to the melting points of copper and silver. Speaking in terms of present day pyrometer scales, it is found expedient to begin this process at somewhere between 1650° and 1800°F. At this temperature, the iron has dissolved the more finely divided part of the combined carbon or carbide and the matrix has become saturated with carbon. Particles of carbon separate on the boundaries between iron carbide and this solution, as shown in Fig. 2. As time goes on, these particles grow at the expense of the adjacent carbide as shown in Fig 3.

Effect of Temperature on Graphite Precipitation

7. The rate at which graphite precipitates increases with temperature, but the completeness of the process decreases. It

FIG. 2—EARLY STAGES OF GRAPHITIZATION OF WHITE CAST IRON. ETCHED WITH PICRAL, x100.

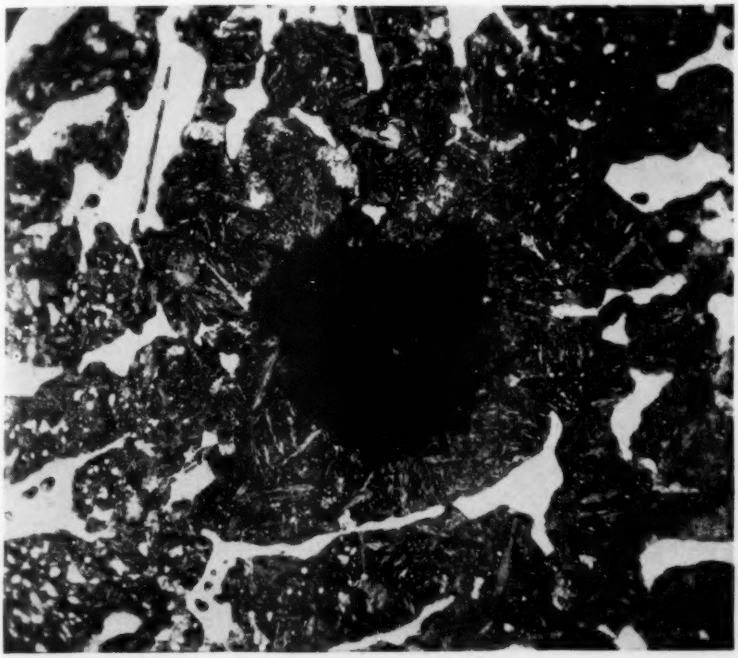

FIG. 3—NODULES OF TEMPER CARBON SURROUNDED BY SPHEROID OF CEMENTITE-FREE AUSTENITE. ETCHED WITH PICRAL, x300.

is therefore necessary at the end of the process to drop the temperature below the so-called A_1 point, which may be found somewhat below 1400°F. in metal such as is encountered in the malleable industry. Below this temperature, carbon is not soluble in iron appreciably and the process can be entirely completed.

8. This completion may take place in two distinctly different ways, depending on how fast the temperature is lowered. If the temperature is lowered rather rapidly, the carbon comes out of solution as iron carbide which deposits itself in lamina or flakes interspersed with similar lamina of iron somewhat like the leaves of a book or the cards of a deck. Note here again an analogy with the freezing conditions. If we freeze rapidly, we get iron carbide as distinguished from graphite and the same thing happens if insolubility in the solid state is involved.

Formation of "Bull's-eye" Structure

9. If now we hold such a supercooled metal some time below

the critical point, the carbide, in its desire to break up, will do so, depositing its carbon on the original graphite nodule; the resulting structure is shown in Fig. 4. If we cool somewhat more slowly, then there is opportunity for the carbon, which is dissolved in iron to make a solid solution, to be precipitated by the decomposition of this solution into iron and graphite. The graphite again deposits on the original nodule which then becomes surrounded by a ring of iron known in the trade as a "bull's-eye" and is shown in Fig. 5. The process can either be conducted slowly enough so that the bull's-eyes formed are so large as to complete graphitization and avoid the formation of the lamellar "pearlite" constituent, or the metal may be held a further time to complete the process by the mechanism illustrated in Fig. 4. The final result is shown in Fig. 6.

10. From what has just been said, it is plain that the graphitizing process involves the solution of "cementite" (iron carbide), its decomposition into its constituent elements, the mi-

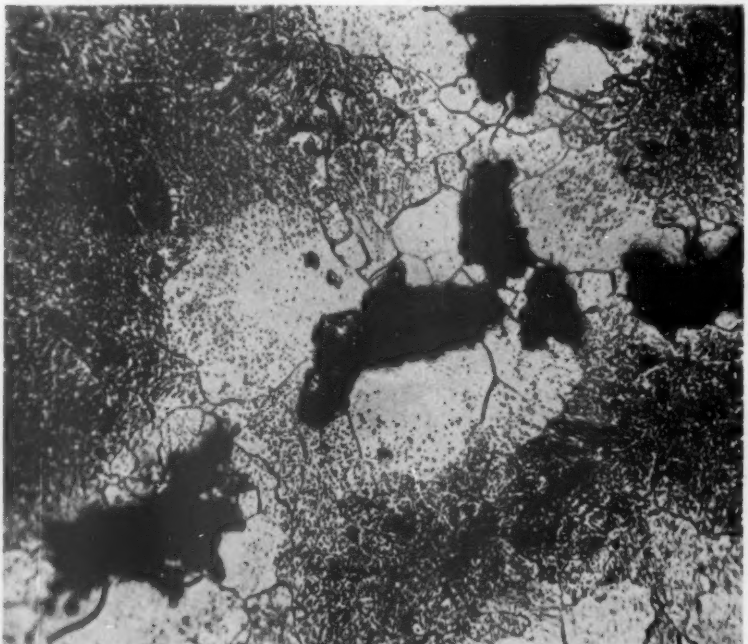

FIG. 4—PRODUCT OF GRAPHITIZATION OF THE CARBON-PEARLITE SYSTEM. ETCHED WITH NITAL, x500.

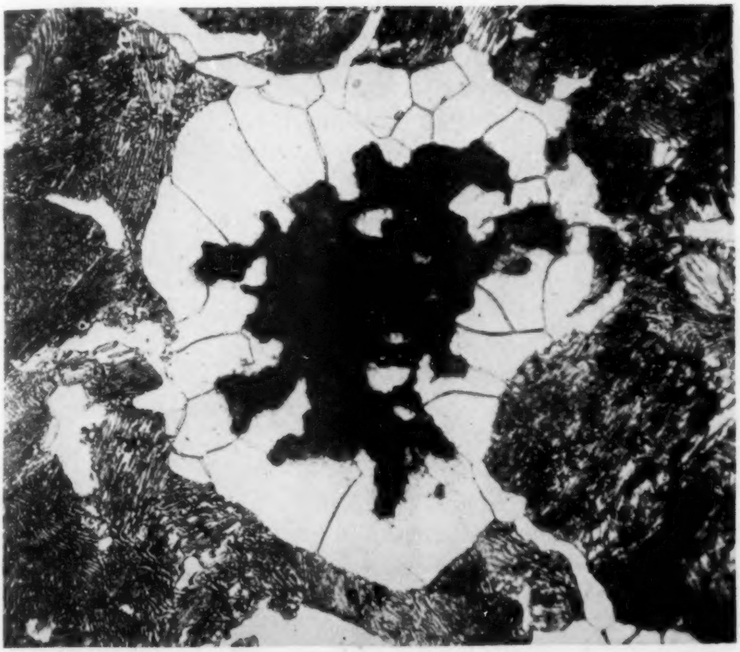

FIG. 5—FERRITE DEPOSITED WITHOUT PASSING THROUGH THE PEARLITE STAGE. ETCHED WITH NITAL, x100.

gration of the carbon to points where it can readily crystallize out and the growth of graphite crystals. We have not touched upon the formation of centers of crystallization beyond pointing to the fact that the nodules always form at the boundary between cementite and solid solution. The number of these centers of crystallization is of great importance, for it is reasonable to expect that more carbon will come out on many centers of crystallization than on but few. It has been found that the number of carbon nodules does not change materially during the graphitizing process. This is rather surprising, but fortunate, because we do not have to reckon with changes in nodule number while the process is going on.

Factors Influencing Number of Nodules

11. The number of nodules which form in a unit of volume in any given iron is quite a complex matter and is not yet well understood. In the first place, since the nodules always form at the surface of iron carbide, the opportunity of getting a great

number increases when the iron carbide in the original hard iron is finely subdivided. It is very well known that if white iron is heated to 1700° or 1800°F. and rapidly cooled, cementite distribution does not appear to be changed, but the number of nodules formed in annealing may be multiplied several thousand times. No perfectly demonstrable explanation for this phenomenon exists, but very possibly it is associated with the formation of a very finely spheroidized cementite distribution formed when the supercooled white iron is again heated. An increase in nodule number has also been observed when the oxygen content of iron was increased. There is some possibility that the graphite nodule actually grows around an oxide or sulfide particle which has been rejected to the surface of a cementite grain.

The Nucleus Formation Problem

12. The problem of what constitutes a nucleus or center of crystallization is always complex and in connection with graphitization is but very superficially understood. The nodule number also

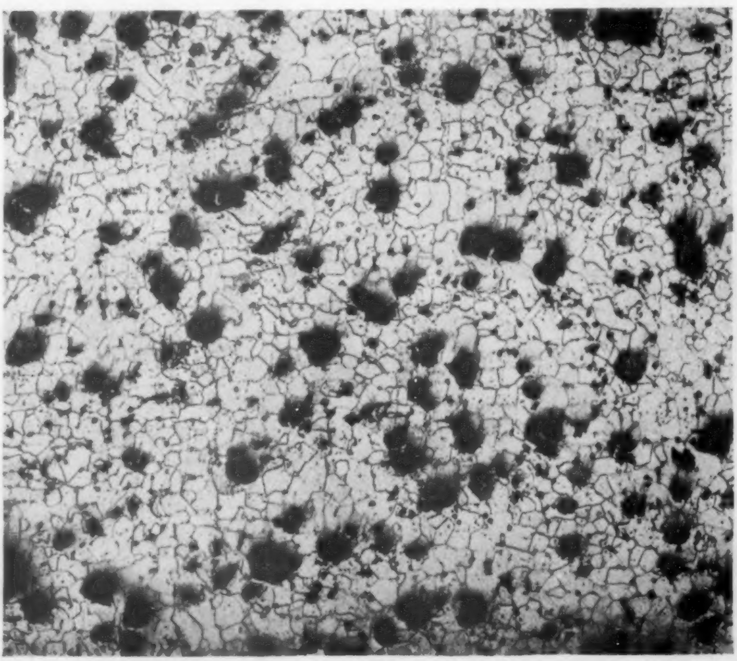

FIG. 6—MALLEABLE CAST IRON. ETCHED WITH NITAL, x100.

increases with the temperature at which the nucleization begins.

13. Returning now to the thought that graphitization consists of the solution of cementite, its dissociation, the migration of carbon and its deposition, the thought immediately suggests itself that these several processes may not be similarly affected by changes of temperature or changes of composition. It is quite obvious that the process as a whole will go on at the rate set for it by that at which the slowest of the four enumerated processes goes on under the existing circumstances. There is no experimental evidence as yet that the solution of cementite is ever the slowest of the four. There is quite good evidence that the graphitizing process always begins at a rate determined by the crystallization velocity of graphite. It continues to be governed by this consideration usually for an extremely short time and never for a very long one. Next, and often for most of the deposition of graphite, it is governed by the rate of migration of carbon, but always concludes with a longer or shorter interval in which dissociation rate is the controlling factor.

14. The rate of formation of graphite at a given temperature as time goes on under the conditions which have been described is capable of mathematical analysis. The treatment is by no means abstruse but quite tedious and unavoidably results in complex algebraic equations. In terms of such equations the relation of the amount of graphite formed to time can be quite completely described.

Additional Constants Influencing Graphitization

15. Aside from the nodule number and the carbon content, there are involved four important constants. The linear rate of crystallization of graphite, the dissociation rate of cementite, the migratory rate of carbon in solution in iron and the rate of solution of cementite. Any complete understanding of how chemical composition and temperature affect graphitizing rate will be possible only when the effect of these variables on each of the four constants enumerated has been completely worked out. Since the mathematical treatment underlying this view was published only last October, it is not surprising that much remains to be done in this direction before we can completely plan what to expect during graphitization under a particular set of circumstances.

16. The only information now available as to the effect of va-

rious things on annealing time is found in investigations which view the process as a whole. It is not especially surprising, therefore, that there should be uncertainties and contradictions, some of which would be accounted for if we pay careful attention to the tests by which individual investigators judge the changes in graphitizing rate. No one has done this with any great degree of completion. It is necessary to consider the effect upon the rate at various stages of completion and at various temperatures. No simpler investigation suffices to tell a complete story.

DIFFICULTIES OF GRAPHITIZING RATE INVESTIGATIONS

Chemical Analysis Difficulties

17. The investigation of graphitizing rates is beset with a number of annoying difficulties. It is impossible to sample a material containing graphite and reduce it to chips without losing very considerable amounts of the graphite (sometimes as much as one-third). This does not interfere with the accurate determination of combined carbon by taking the difference between the total carbon and graphite of a properly mixed sample, but the graphite content directly determined will be grossly in error. It might be corrected by taking the difference between the calculated combined carbon and the original total carbon. It is much better to work with samples in the form of solid pieces. With modern combustion furnaces, these can be readily burned and their solution for the graphite determination need not be too time-consuming.

18. Frequently graphitization does not occur with such uniformity that a sample, weighing say one gram, can be considered as representing what has gone on as the average of a larger piece. The analytical procedure possibly sets a limit as to how far the size of sample can be increased; therefore it is frequently necessary to analyze many samples in order to obtain a usable average.

Disadvantages of Expansion Method

19. Some have measured the process of graphitization by measuring the expansion of the iron due to the liberation of carbon; this has many advantages, chief of which is that information is obtained concerning a rather large volume of metal. Unfortunately, it is somewhat doubtful whether the expansion of an iron is directly proportional to the per cent of graphite formed.

Electric Resistance Method Presents Difficulties

20. Measurements of electric resistance could be used similarly but are still more doubtful in interpretation. There are also very great difficulties in preventing the specimen from losing carbon while it is graphitizing with an accompanying error for which we can hardly compensate since we do not know whether the carbon was lost before or after graphitization. To get any kind of results at all, the original hard iron samples must be very carefully prepared as to uniformity of composition and cooling rate.

21. Let the reader be warned that any experimentation with graphitizing rates in which these precautions are ignored will not lead to any result worthy of great confidence. The field is not one for an investigator who has not good facilities at his disposal, nor is it one in which the analytical work can be entrusted to the type of man found in the usual control laboratory.

Comments on Metallographic Methods

22. Several observers have depended upon metallographic evidence for the recognition of the beginning or the end of the graphitizing process. It is perfectly true that the microscope will see particles of graphite or cementite too small to be detected by the chemist. However, when very few such particles exist, the likelihood that any of these few will appear in the polished surface becomes very small, so that the precision of the microscopic technique is thereby much reduced. Indeed the recognition of the time for completion of graphitization is practically difficult and theoretically impossible. The reaction always proceeds extremely slowly near the end so that great errors in time correspond to very small errors in graphite content. Theoretically, an infinite time is required under any circumstances for the complete attainment of the equilibrium in the process. It is rather unusual either in practice or in the laboratory to carry the graphitization much further than a combined carbon content of 0.03 to 0.05 per cent.

Comments on Methods Dependent on Observation of First Graphite

23. A few observers have heated white iron at a predetermined rate, usually a rather slow one, and attempted to use the temperature at which graphite was first recognized as a criterion of annealibility. This approach to the subject is entirely indefensible. There is no temperature analogous to the critical temperatures of the iron-

carbon diagram at which graphitization begins. The temperature recorded by such experimenters is that at which the amount of graphite just recognizable by their particular procedures is that formed during the total time from the beginning of heating to the time when the recorded temperature is reached. If the heating rate be reduced the temperature will come out lower and does not approach any particular limit in value.

CAUSES FOR VARIATIONS IN GRAPHITIZING RATE

24. With this cursory and superficial outline of the pitfalls besetting the student of graphitization to guide him in his interpretation of the conclusions of various investigators, the reader will no doubt desire some discussion as to the causes for variations in graphitizing rate. With the suggestion that those who really desire detailed knowledge of the subject should read the original source material in the light of the preceding discussion of investigational methods, one may sum up with reasonable satisfaction what has been learned on the subject. It must at all times be remembered that the investigators who have so far published their results have made no distinction between the various mechanisms which govern graphitization at different stages of the process.

Nodule Number

25. The first variable is the nodule number. This has already been discussed at an earlier stage of the present paper. It is a characteristic both of the metal and of the temperature at which graphite formation begins. The carbon content is of relatively little consequence in the first stage of graphitization so far as the time for the completion of graphitization is concerned. The relation of graphitizing rate to carbon content is such that the rate increases when the carbon content increases. There is exact proportionality only for the dissociation control stage of the process but there is some compensation in the migratory rate stage. The presence of the large surface of graphite nodules corresponding to much graphite is of benefit in promoting the speed of the graphitizing process when the temperature falls below A_1, the critical point. It is thus generally an approximation, usually believed, that the second stage of annealing is faster the higher the total carbon.

Effect of Alloying Elements

26. A great number of alloying elements affect graphitizing rate favorably or unfavorably. The elements silicon, aluminum, titanium, zirconium, nickel, copper and uranium are all very definitely known to accelerate the graphitizing rate when present in not too great a quantity. Some of these, aluminum, titanium and zirconium in particular, are effective accelerators even when present in amounts of only some hundredths of a per cent. The fact that our knowledge of the effect of oxygen on graphitizing rate is as yet but cloudy and that many of the elements referred to above are strong deoxidizers, has led to considerable speculation as to whether the effect of these elements is due to their presence or to the fact that they have removed oxygen. There is here room for much painstaking work before a real conclusion can be reached. There is, of course, no reason to believe that nickel or copper could act in this way and gold, which is known to be a mild accelerator, would also certainly not be a deoxidizer.

27. On the other hand, manganese, which is a rather powerful deoxidizer, is a retarder of graphitization along with chromium, molybdenum, vanadium, and in a mild degree, tungsten. Many observers have begged the question and said that these elements were retarders because they form stable carbides. This is merely saying that they are retarders because they prevent graphitization, which adds nothing to the original statement.

28. It is to be borne in mind that titanium carbide is a very stable compound and silicon carbide is stable enough to exist, so that the problem can not be dismissed nearly as simply as the coiners of the stable carbide phrase expect. Certainly in the case of manganese and chromium, and possibly in the case of molybdenum, the retarding effect is relatively much less at high temperatures than at low temperatures. An increment of one-half or three-quarters per cent of manganese above the orthodox value retards the first stage of annealing but little, but slows up graphitization in the second stage quite markedly. Use is made of this well-known fact in the production of the arrested anneal malleables.

The Film Theory of Graphitizing Retardation

29. The elements boron, sulphur, selenium, and tellurium when present in considerable quantity are all retarders of graphitization apparently because their compounds with iron form films surround-

ing the carbide particles. While there is little convincing visual evidence of the existence of these films, there is much indirect knowledge making this hypothesis plausible. It is very possible that only when these films do exist does the solution rate of cementite become effective in controlling annealing rate. Some time-graphite curves for high sulphur iron have been published which would be explicable on this basis. In the presence of sufficient manganese, the sulfide, selenide and telluride of iron are unstable, exchanging their iron for manganese. The resulting manganese compounds have solubility and fusibility characteristics which prevent their separation on the cementite surfaces but cause them to form separate "blobby" inclusions which do not materially affect graphitizing rate. Hence the need for a proper balance of manganese and sulphur or of manganese and selenium and tellurium in the unusual case when these are present. Strangely enough boron, selenium and tellurium have all been alleged to favor graphitization when present in traces.

30. Cerium, and no doubt the other rare earths, act similarly to manganese in forming innocuous compounds with sulphur and similar elements. It will remove these elements even from their compounds with manganese, liberating an equivalent amount of manganese which can act as a retarder. Tin will remove sulphur from its compounds with iron or manganese so that, when present in iron, it will form films of a tin-sulphur compound on carbides even though enough manganese to balance the sulphur is present. In so doing, it also, of course, liberates manganese and we may get the combined retarding effect of a sulfide film and a manganese excess. Cerium sulfide, however, is more stable than tin sulfide, so that tin cannot form sulfide films in the presence of cerium. The fact that graphitization can be effected by the joint presence of sulphur, manganese, tin and cerium (one or more) in iron just as can be predicted from their chemical equivalents in combining, is one of the strong arguments in favor of the film theory. These alternate retardations and accelerations of anneal as one metal and then another is added have actually been followed completely in the laboratory.

EFFECTS OF GASES ON GRAPHITIZATION

31. Hydrogen originating with moisture in the blast, hydrogen in the fuel, or rust in the charge, is of great and peculiar effect in annealing. It is rather well known that it interferes with the

migratory rate of carbon in iron. It will escape from white iron in the annealing process almost completely and probably very early, unless there be hydrogen in the annealing furnace atmosphere. It is present in hard iron in amounts rarely as great as one-one-thousandth of a per cent, but if this per cent is not reduced, annealing is much retarded.

32. Oxygen in the iron, originating either in the melt or from the annealing atmosphere, may affect graphitizing rate, although no one knows much about it. There is certainly evidence that it may accelerate graphitization, when coming from the melt, by increasing nodule number. There is both practical experience and research knowledge that cementite contaminated with oxygen is actually stable and not metastable, *i.e.,* it will not dissociate into iron and carbon. Particles of such stabilized "oxy-cementite" are frequently seen near shrinkage voids or in oxidized surfaces in malleable castings.

EFFECTS OF VARIOUS ATMOSPHERES ON GRAPHITIZATION

33. This brings us naturally to the question of environment in annealing. It appears well established that annealing rate varies with the gas by which the metal is surrounded while being heat treated. Presumably one should use as the standard of reference, graphitizing rate in vacuum. It is well established experimentally that if the surrounding atmosphere contains oxygen or has access to oxygen in the form of solid packing, the gas will promptly take a composition determined by the temperature. Neglecting the inert nitrogen of the air, the gas will contain carbon dioxide and carbon monoxide in a definite and predictable proportion determined by its having saturated itself with carbon from the iron. The actual ratio depends upon temperature and pressure. So long as the temperature is above about 1400°F., the gas composition will be such that the scaling of iron is impossible. When the temperature falls below a particular point in that region, scaling is inevitable, assuming the presence of any oxygen even though combined with carbon.

34. We have already alluded to the fact that annealing in hydrogen is slow and the same can be said of annealing in gases such as anhydrous ammonia or acetylene, which decompose into their elements at annealing temperatures. It is quite certain that the presence of *mixtures* of CO_2 and CO accelerate annealing and

it is reasonably certain that under high pressures this is not true below the critical point. One may speculate as to the role played in this latter phenomenon by the formation of oxy-cementite in pearlite.

EFFECT OF OXYGEN IN ANNEALING POTS

35. In view of the fact that the oxygen in an annealing pot takes carbon from the metal, the effect upon the casting is worth at least passing notice. The carbon, of course, comes from the surface of the casting and is replenished from within but not nearly at the rate at which it is removed. Castings annealed in an atmosphere in which the ratio of the weight of oxygen with which the casting comes in contact during the annealing process to the weight of casting is anything but insignificant, are therefore commonly possessed of a decarburized surface. This carbon was removed as cementite and thus minimized the opportunity for the formation of nodules of graphite near the surface. The result therefore is slower graphitizing rate of the surface metal than of the interior metal, which may have been further affected by the absorption of some oxygen.

36. The rims at the end of the first stage of annealing may have consisted almost completely of solid solution. When the temperature is dropped for the second stage of annealing, the carbon in this solid solution finds no nodules upon which to crystallize and so comes out as pearlite, which can be but slowly graphitized thereafter because of the long migratory path the carbon must take to get to existing nodules or the poor opportunity for the creation of new nodules in the decarburized rim. If decarburization and graphitization are not too badly out of balance, the rim consists merely of a narrow band of iron which is slightly objectionable from the machining point of view and slightly favorable to a good ductility.

EFFECT OF NUMBER OF NODULES ON PHYSICAL PROPERTIES

37. The number and form of nodules is also of some significance with regard to the physical properties of the resulting product. Nodules growing at high temperature are not very compact, but incline to be sprawly and "crab-like." The iron between the branches of such nodules adds nothing to the strength of the material and these nodules are, in their effect on the mechanical prop-

erties, approximately equivalent to a much greater amount of carbon such that it would fill the space occupied by the existing graphite and the iron which that encloses.

Effect of Number of Nodules on Tensile Strength

38. Nodules which grow at low temperature, and particularly below the critical point, on the other hand, are very dense and solid. It is quite possible by careful though tedious microscopic methods to get at least qualitative evidence of the relation between "density of packing" of graphite in a nodule, which is a measure of its sprawliness, and the physical properties. It is generally supposed that small temper carbon nodules should make a better product. The problem has been investigated and no marked relation between number of nodules and tensile strength has been detected. It may be that this is true because, except in special cases, the smaller nodules are also the sprawlier. The exception is metal which has been prequenched before annealing in which the nodules are small and dense and the metal is rather strong.

Effect of Number of Nodules on Ductility

39. The ductility of malleable iron increases as the size of the particle increases. Whether this is directly cause and effect or due to the fact that very large nodules are grown only when annealing at very low temperature, is not certain. There is evidence in favor of the view that the properties of malleable iron are improved if it be held for some time below the critical point after graphitization is complete. The two phenomena may have some relation.

Some Effects of Melting Operations

40. The present program, at least by implication, is limited in scope to malleable iron properly so called and to the annealing process. There remain, however, certain closely related subjects not falling strictly within the Symposium's field which should properly be considered in the same connection.

41. The first of these concerns the melting operation. Without going into any detailed discussion of this subject, one may point out that since the melting operation may, in part, determine the oxygen and hydrogen contents of the resulting product, a study of the effects of gases on graphitization may lead one back to a

relation of graphitizing rate to the chemistry of the melting process. We have already spoken of the fact that graphite requires a nucleus upon which to grow; this nucleus can be an oxide, and if it is, the amount and distribution of nuclei can be related to the melting process.

42. Furthermore, it is quite well known that graphitizing rate may depend upon the amount of graphite in the melting furnace charge. It may even depend on when that graphite was introduced. An explanation based upon the persistence of very small fragments of graphite for some time in a liquid melt is very attractive, although there has been a considerable amount of argument as to its validity. In any event, there is much evidence that if graphite-bearing materials are added to liquid iron shortly before pouring, annealing is facilitated and even primary graphitization may be initiated.

43. The effect of melting temperature upon the destruction of nuclei, whether of graphite or of other sorts, has been studied and could be introduced perhaps as at least indirectly affecting the annealing process.

44. Even the refractory upon which the iron is melted enters into a consideration of the graphitizing reaction, since it is well known that, other things being equal, graphitization is easier the more acid the furnace lining.

COMMENTS ON OTHER GRAPHITIZABLE MATERIALS

45. There are also materials which are not cast irons but steels, which are willfully subjected to partial or complete graphitizing by annealing. The most satisfactory definition of a steel, so far as this writer is concerned, is that a steel is an alloy of iron and carbon, possibly including other elements also, which is homogeneous at at least some one temperature below the melting point. Neglecting the effect of alloying elements, this means that iron-carbon alloys containing less than 1.76 per cent carbon are steels, for on being heated to a particular temperature (the eutectic melting point) any graphite or cementite which they contain goes completely into solid solution, but melting does not occur.

Graphitizable Steels

46. The commercial graphitizable steels contain from something

under 1 per cent of carbon up to perhaps something less than 1.5 per cent carbon. Their silicon content may be from nearly 1 per cent to perhaps something over 1.5 per cent. They are non-eutectiferous, that is to say they develop no massive (eutectic) cementite on freezing. When they are heated for the purpose of annealing to a temperature falling into the same range as the temperature of the first stage of malleable annealing, they contain no excess of cementite. Graphitization can, therefore, not begin by the deposit of graphite at the junction of cementite and solid solution.

47. Apparently in such material, nuclei form around oxides or sulfides. The nuclei may not form at all at the upper temperature if the solid solution is not supersaturated toward graphite. If they do not form at this higher temperature, they will do so while cooling to the A_1 point, for all the steels commercially made for the purpose we are now discussing, contain more than the eutectoid ratio of carbon. Below the critical point, the graphitizing phenomenon runs parallel to that in the annealing of white cast iron. The steels may be completely graphitized or, more commonly, combined carbon is purposely retained somewhat as in the pearlitic malleables.

48. In the latter case, the heat treatment in the second stage of annealing must be so controlled as to give the desired metallography to the metallic matrix of the resulting product. It may be that lamina are desired or spheroids. Since very generally a particular concentration of combined carbon is also needed, it is necessary to so control the chemical compositions that the heat treatment which produces the proper structure in the matrix also produces that degree of graphitization which will leave the requisite amount of combined carbon. Gross segregations of ferrite, as in the bull's-eye type of pearlitic malleable, are usually avoided.

Other Factors Influencing Graphitizing Rate

49. Experiments in connection with graphitization in material having the carbon concentration of these graphitizable steels have laid emphasis upon two other factors determining graphitizing rate which have not received a great deal of attention in connection with white cast iron. One of these is the grain size of the dispersed cementite phase and the other is the effect of internal stress on graphitizing rate.

50. Evidently, if during freezing, a solid shell is set up around

a casting whose temperature is of necessity lower than that of the interior, then if the interior be also solid, tensile stresses in three dimensions will later be set up inside the casting tending to expand the solid material of the interior and increase its volume. The outer layers meanwhile may very possibly be under considerable compression. Since the formation of graphite from cementite is accompanied by an increase of volume, it would be facilitated by such three dimensional tension stresses. Qualitatively, at least, a relation has been observed between conditions which should produce stresses in the metal and graphitizing rate. In the early stages, while the center is under compression, graphitization there and then would be temporarily retarded.

Bibliography

Schenck, Rudolph, "*Gleichgewichtsuntersuchungen uber die Reduktions-Oxydations-und Kohlungsvorgange beim Eisen, IV and V*", ZEIT. FUR ANORGANISCHE UND ALLGEMEINE CHEMIE, vol. 167, pp. 254 and 315 (1927).

Maxwell and Hayes, "*The Free Energy and Heat of Formation of Iron Carbide for the Temperature Interval 650° to 700°*", JOURNAL, American Chemical Society, vol. 48, p. 584 (1926).

Schwartz, H. A., "*The Metastability of Cementite*", TRANSACTIONS, American Society for Metals, vol. 23, p. 126 (1935).

Chipman, John, Discussion of "*The Metastability of Cementite*", TRANSACTIONS, American Society for Metals, vol. 23, p. 155 (1935).

Watase, Takeo, "*Heat of Formation of Cementite*", SCIENCE REPORTS, Tohoku Imperial University, vol. XVII, p. 1091 (1928).

Schwarz, C., "*Warmetonungen Metallurgischer Reaktionen*", ARCHIV FUR DAS EISENHUTTENWESEN, vol. 6, p. 229 (1932).

Umino, Saburo, "*The Specific Heat of Carbon Steels*", SCIENCE REPORTS, Tohoku Imperial University, vol. XV, p. 331 (1926).

Naeser, Gerhard, "*Die Specifische Warme des Eisenkarbides Fe_3C*", MITTEILUNGEN AUS DEM KAISER WILHELM INSTITUT FUR EISENFORSCHUNG, vol. XVI, p. 207 (1934).

Schwarz, Carl, and Ulich, Hermann, "*Specifische Warme, Entropie und Bildungsarbeit des Eisenkarbides Fe_3C*", ARCHIV FUR DAS EISENHUTTENWESEN, vol. 10, p. 11 (1936).

Austin, J. B., "*Heat Capacity of Iron*", INDUSTRIAL AND ENGINEERING CHEMISTRY, vol. 24, p. 1225.

Austin, J. B., "*A Thermodynamic Study of the Iron-Carbon Diagram*", Metals and Alloys, vol. IV, p. 49 (1933).

Wells, Cyril, "*Graphitization in High Purity Iron-Carbon Alloys*", TRANSACTIONS, American Society for Metals, vol. 26, p. 289 (1938).

Mehl, R. F., and Wells, Cyril, "*Constitution of High-purity Iron-Carbon Alloys*", TRANSACTIONS, American Institute, Mining and Metallurgical Engineers, Iron and Steel Division, vol. 125, p. 429 (1937).

Schwartz, H. A., Payne, H. R., Gorton, A. F., and Austin, N. M., "*Condition of Stable Equilibrium in Iron-Carbon Alloy*", TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. LXVIII, p. 916 (1923).

Kinzel, A. B., and Moore, R. W., "*Graphite in Low Carbon Steel*", TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 116, p. 318 (1935).

Wark, "*Bestimmung der Loslichkeitslinie des Eisenkarbides (Fe_3C) in gamma-Eisen*", Metallurgie, vol. VIII, Part 22, p. 704 (1911).

Ruer and Ilgin, "*Zur Kenntnis des stabilen Systems Eisen-Kohlenstoff*", Metallurgie, vol. VIII, Part 4, p. 97 (1911).

Heyn, E., "*Theorie der Eisen-Kohlenstoff Legierungen*", Velag von Julius Springer, Sec. 3 (1924).

Schutz, E., and Stotz, R., "*Der Tempergusz*", Julius Springer (1930).

Schwartz, H. A., "*Graphitization at Constant Temperature*", TRANSACTIONS, American Society for Steel Treating, vol. 10, p. 53 (1926).

Schwartz, H. A., and Barnett, Martin, "*The Initial Stages of Graphitization*", TRANSACTIONS, American Society for Metals, vol. 26, p. 358 (1938).

Schwartz, H. A., "*The Metallographic Determination of the Size Distribution of Temper Carbon Nodules*", Metals and Alloys, vol. 5, p. 139 (1934).

Scheil, Erich, "*Die Berechnung der Anzahl und Groszenverteilung kugelformiger Kristalle in undurchsichtigen Korpern mit Hilfe der durch einen ebenen Schnitt erhalten Schmittkreise*", ZEIT. FÜR ANORGANISCHE UND ALLGEMEINE CHEMIE, vol. 201, p. 259 (1931).

Schwartz, H. A., "*A Simple Approximate Method for Determining Nodule Number*", Metals and Alloys, vol. 7, p. 278 (1936).

Ishiwara, Torajiro, "*The Effect of Impurities on the Dendritic Structure in Carbon Steels and their Diffusion at High Temperature*", SCIENCE REPORTS, Tohoku Imperial University, vol. 12, p. 327 (1924).

Fisher, E., "*Relation of Temperature to Form and Character of Graphite Particles in the Graphitization of White Cast Iron*", TRANSACTIONS, American Foundrymen's Association, vol. XXX, p. 397 (1922).

Schwartz, H. A., and Ruff, Wolfram, "*Origin and Growth of Graphite Nuclei in Solid and Liquid Iron Solutions*", TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 120, p. 217 (1936).

Schwartz, H. A., and Junge, C. H., "*A Note on the Metallography of Ferrite in Malleable Cast Iron*", TRANSACTIONS, American Foundrymen's Association, vol. XLII, p. 94 (1934).

Schwartz, H. A., "*Nucleization of Graphite by Manganese Sulphide*", Metals and Alloys, vol. VI, p. 328 (1935).

Boegehold, A. L., "*Factors Influencing Annealing of Malleable Iron*", TRANSACTIONS, American Foundrymen's Association, vol. XLVI, p. 449 (1938).

Schwartz, H. A., U. S. Patent No. 1,688,438 (1928).

Saito, Daikichi, and Sawamura, Hiroshi, "*A New Phenomenon concerning the Graphitization of White Cast Iron and its Application to the Manufacture of Black Heart Malleable Castings*", MEMOIRS, College of Engineering, Kyoto Imperial University, vol. V, p. 2 (1927).

Schwartz, H. A., Johnson, H. H., and Junge, C. H., "*Graphitization of Prequenched White Cast Iron*", TRANSACTIONS, American Society for Steel Treating, vol. 17, p. 383 (1930).

White, A. E., and Schneidewind, R., "*Effect of Superheating on the Annealing of Malleable Iron*", TRANSACTIONS, American Foundrymen's Association, vol. 41, p. 98 (1933).

Schwartz, H. A., Johnson, H. H., and Junge, C. H., "*The Retarding Effect of Certain Metallic Elements on Graphitization*", TRANSACTIONS, American Society for Metals, vol. 25, p. 609 (1937).

Schwartz, H. A., "*Graphitization in the Presence of Nickel*", TRANSACTIONS, American Society for Steel Treating, vol. 15, p. 957 (1929).

Hayes, Anson, and Flanders, H. E., "*Structural Evidence of an Iron-Carbon Eutectoid*", TRANSACTIONS, American Society for Steel Treating, vol. 6, p. 623 (1924).

Schwartz, H. A., and Junge, C. H., "*Metallographic Changes during Cooling between the First and Second Stages of Annealing*", TRANSACTIONS, American Foundrymen's Association, vol. XLIV, p. 507 (1936).

Schwartz, H. A., Van Horn, Kent, and Junge, C. H., "*Transformation in the Carbide Phase during Graphitization*", TRANSACTIONS, American Society for Steel Treating, vol. 21, p. 463 (1933).

Schwartz, H. A., U. S. Patent No. 1,640,674.

Sawamura, Hiroshi, "*Influence of Various Elements on the Graphitization in Cast Iron*", MEMOIRS, College of Engineering, Kyoto Imperial University, vol. IV, No. 4 (1926).

Lorig, C. H., and Smith, C. S., "*Effect of Copper in Malleable*", TRANSACTIONS, American Foundrymen's Association, vol. XLII, p. 211 (1934).

Levy, Donald M., "*Iron, Carbon and Sulphur*", JOURNAL, Iron and Steel Institute, vol. LXXVII, p. 33 (1908).

Leroyer, Maurice, "*La Malleable*", Dunod, p. 42 (1936).

Schwartz, H. A., and Guiler, G. M., "*Chemical Elements Inhibiting Graphitization*", TRANSACTIONS, American Foundrymen's Association, vol. XXXIII, p. 639 (1925).

Symposium on Pearlitic Malleable Cast Iron, American Society for Testing Materials, p. 18 (1936).

Schwartz, H. A., U. S. Patent No. 1,660,398.

Boyles, Alfred, "*The Freezing of Cast Iron*", TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 125, p. 141 (1937).

Honda, Kotaro, and Murakami, Takejiro, "*On Graphitization of Iron-Carbon Alloys*", JOURNAL, Iron and Steel Institute, vol. 102, Part II, p. 287 (1920).

Hayes, Anson, and Scott, C. G., "*The Catalysis of the Graphitization of White Cast Iron by the Use of Carbon Monoxide-Carbon Dioxide*

Mixtures when applied under Pressure", TRANSACTIONS, American Foundrymen's Association, vol. XXXIII, p. 574 (1926).

Schwartz, H. A., U. S. Patent No. 1,656,535.

Schwartz, H. A., Guiler, G. M., and Barnett, M. K., "*Significance of Hydrogen in the Metallurgy of Malleable Cast Iron*", TRANSACTIONS, American Society for Metals, vol. 28, p. 811 (1940).

Kikuta, Tario, "*On the Malleable Cast Iron and the Mechanism of its Graphitization*", SCIENCE REPORTS, Tohoku Imperial University, vol. XV, p. 115 (1926).

Schwartz, H. A., U. S. Patent No. 1,640,674.

Schwartz, H. A., and Barnett, M. K., "*The Velocity of Conversion of Austenite to Ferrite and Cementite*", Preprint of American Foundrymen's Association (1941).

Ziegler, N. A., Meinhart, W. L., and Deacon, A. J., "*Graphitization of Cementite in Cupola White Iron*", Preprint of American Foundrymen's Association (1941).

Boegehold, A. L., "*Some Unusual Aspects of Malleable Iron Melting*", TRANSACTIONS, American Society for Metals, vol. 26, p. 1084 (1938).

Howe, Henry M., "*The Carbon-Iron Diagram*", TRANSACTIONS, Institute of Mining Engineers, vol. XXXIX, p. 3 (1908).

White, A. E., and Archer, R. S., "*The Annealing of Malleable Castings*", TRANSACTIONS, American Foundrymen's Association, vol. XXVII, p. 351 (1918).

White, A. E., and Gladhill, H. E., "*Influence of Temperature and Composition on Graphitization of White Cast Iron*", TRANSACTIONS, American Foundrymen's Association, vol. XXX, p. 413 (1922).

Schwartz, H. A., "*The Conversion of Solid Cementite into Iron and Graphite*", JOURNAL, Iron and Steel Institute, vol. CXXXVIII, No. II, p. 205P (1938).

Schwartz, H. A., "*The Kinetics of Graphitization in White Cast Iron*", A.S.M. Preprint (1941).

Austin, C. R., and Norris, B. S., "*Effects of Small Amounts of Alloying Elements on Graphitization of Pure Hypereutectoid Steels*", TRANSACTIONS, American Society for Metals (1941).

Kelhy, K. K., "*Contributions to the Data on Theoretical Metallurgy, VIII, the Thermodynamic Properties of Metal Carbides and Nitrides,*" U. S. Bureau of Mines BULLETIN 407 (1937).

(*Discussion for entire Symposium will be found on pages 133-148, inclusive.*)

The Suppression of Graphitization by Supercooling

By C. H. Junge*, Cleveland, Ohio

Abstract

The author first reviews the sequence of events in the freezing of a liquid, using a pure metal as the example, covering crystallization, known as undercooling, supercooling or surfusion, and nuclei formation. He states that it is impossible to suppress the freezing of a metal indefinitely because forces promoting solidification are so powerful at certain temperatures that crystallization cannot be prevented. The author then describes what happens during the freezing of a liquid iron containing silicon and carbon. He explains the phenomenon of white and gray iron by discussing the supercooling effects in the iron-carbon system and stresses the importance of undercooling in the suppression of graphite formation. Tables are given showing summary of temperature data and the influence of temperature of solidification on the graphite pattern in a gray iron. Conclusions reached by the author are listed.

1. Before discussing the influence of undercooling in suppressing graphitization during the freezing of a cast iron, it may be well to review the general sequence of events in the freezing of a liquid. In the interest of simplicity, a pure metal will be chosen as the example.

Freezing of Pure Metal

2. In such a pure liquid at a temperature well above the freezing point, the atoms are in a constant state of rapid motion. Although they make frequent contact with one another, there is no tendency for them to combine, for the forces of repulsion exceed the forces of attraction. However, as the temperature is lowered and approaches the freezing point, the velocity of motion of the atoms decreases and the attractive forces begin to increase.

3. Occasionally now at particularly favorable locations, atoms begin to combine to form extremely minute fragments of crystals. At first these crystal fragments have only temporary existence,

* National Malleable and Steel Castings Co.

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but as the temperature is lowered further, the attractive forces increase further, and many more of them will be formed. When a point is reached where these crystal fragments, or nuclei, as they are sometimes called, become stable enough to attract other atoms to them, then crystallization proper has started. Since the small fragments are less stable than the larger fragments formed later, a lower temperature is required to initiate crystallization than to continue it once it has begun. The phenomenon is called undercooling, supercooling, or surfusion.

4. When a nucleus begins to freeze more solid material around it, heat is liberated in the immediate vicinity and the temperature rises locally, making it unfavorable for new nuclei to form nearby, so that in general, additional nuclei will be formed at cooler locations remote from already existing nuclei.

5. If the abstraction of heat from the liquid is done slowly, the heat liberated by the freezing out of solid matter will be sufficient to raise the liquid from the temperature to which it has supercooled, back to the true freezing temperature, which is the highest temperature at which freezing can proceed. If heat is removed faster than it can be liberated by the freezing process, the liquid necessarily will fall in temperature until a point is reached where the heat liberated by the freezing out of solid matter is just equal to the heat removed from the metal by the surroundings. Actually this balance between heat liberated and heat lost is continually taking place during the entire course of freezing.

6. Since crystallization rate and rate of nuclei formation both tend to increase with increasing amounts of supercooling, it is impossible to suppress the freezing of a metal indefinitely. When a certain temperature is attained, the forces promoting solidification are so powerful that crystallization cannot be prevented in metals as it can in the case of some substances, such as glass, which is a true supercooled liquid.

7. In general, slow cooling of a liquid gives rise to a few crystals large in size, since few nuclei accompany a small amount of undercooling. Rapid cooling produces a great number of small crystals because many nuclei accompany large degrees of undercooling.

Freezing of Liquid Cast Iron

8. We are now in a position to see what happens during the freezing of a liquid cast iron, which is a solution of liquid iron containing silicon and carbon. The atoms in this liquid are in a state

of violent agitation. When this alloy begins to freeze, it desires to become solid iron (in which some carbon is dissolved) and graphite which it can accomplish by a sorting-out process on an atomic scale analogous to separating a shuffled deck of cards into two piles, one of red cards and one of black. Obviously this process requires a certain amount of time. In general, the higher the temperature, the faster the speed of sorting. If the alloy, by faster cooling, is not allowed sufficient time at a high enough temperature for the carbon and iron atoms to be sorted out, no solid material will form, and the temperature of the liquid will decrease with an attendant decrease in atomic mobility.

9. Finally, a temperature will be reached where the desire to become solid will prevail, and even though the inherent desire of the alloy is to become solid iron and graphite, it will find it easier to become solid iron and cementite. A carbon atom, surrounded by many iron atoms, finds it easier to join up with them to form iron carbide than to seek more atoms of its own kind to form graphite. Thus the urge to solidify has been satisfied, and while the desire to form graphite from the cementite remains even at room temperature, it cannot become operative unless the alloy is heated to a temperature high enough to increase the ability of the atoms to rearrange themselves, as in malleable iron annealing.

10. G. B. Upton[1] has suggested that supercooling effects in the iron-carbon system can explain the phenomenon of white and gray iron in the following manner. He states that the freezing point with varying rates of cooling in the metastable iron-iron carbide system is practically unaffected by the silicon content of the alloy. He further assumes that for low silicon alloys, the solidification temperature in the iron-graphite system drops below that for the iron-iron carbide system with very moderate rates of cooling. For intermediate silicon alloys, it falls below only at high rates of cooling, while with high silicon alloys, it becomes impossible to obtain the metastable system even at extremely high rates of cooling, for the two temperature lines never intersect. While the iron-carbon system does apparently behave as though Upton's hypothesis is correct, there seems little hope of verifying it directly because of experimental difficulties.

Importance of Undercooling

11. Some experiments which do confirm the importance of undercooling in the suppression of graphite formation during

freezing were conducted by Schneidewind and D'Amico[2]. They studied the relation of cooling rate, the attending solidification temperature, and the microstructure of a low carbon-low silicon gray iron poured into a wedge shaped mold of green sand. A number of thermocouples were placed along the center line of the wedge from the thick 2½-in. base to the sharp edge. A series of time-temperature observations were made simultaneously at these several thermocouple stations located in sections of various thickness.

12. In Table 1, page 835 of their paper, reproduced as Table 1 of this paper, the authors have recorded the data derived from their time-temperature curves. It is seen that as the cooling rate of the iron increases, *i.e.*, as one progresses from the thick to the thin edge of the wedge, the solidification temperature continually decreases, until at the faster rates the microstructure becomes first mottled, and then completely white for some 200°F. of supercooling.

Table 1

SUMMARY OF TEMPERATURE DATA OBTAINED FROM WEDGE CASTING

Station No.	*Thickness of Wedge, in.*	*Solidification Temp., °F.*	*Austenite Transformation Temp., °F.*	*Nature of the Iron*
1	0.19	1800	1050	White iron — no graphite
2	0.50	1975	1075	Mottled iron — eutectiform graphite
3	0.875	1990	1300	Gray iron — eutectiform graphite in dendritic distribution
4	1.31	—	1300	About same as (3)
5	1.75	—	1290	Gray iron — normal flake graphite
6	2.31	2030	1286	Gray iron — normal flake graphite

13. In other experiments conducted by the same workers, small amounts of molten iron of the same composition as that of the wedge casting were poured into a small cavity 5/16-in. in diameter and one-in. deep in the center of a massive split mold of steel which was preheated to various temperatures near and below the eutectic temperature. Because of the large mass and high thermal conductivity of the mold, and the relatively small mass of the molten metal used, (10 to 15 gr.) it was thought that the liquid iron was cooled nearly instantaneously to the temperature of the steel mold, after which it proceeded to solidify at this same temperature. Here

it was found again that gray iron of the composition used could be made to solidify completely white if the temperature of solidification was about 200°F. below the eutectic temperature. Table 3, page 847 of the reference, reproduced here as Table 2, shows the complete data for this second series of tests.

Table 2

INFLUENCE OF TEMPERATURE OF SOLIDIFICATION UPON THE GRAPHITE PATTERN IN A GRAY IRON

Heat No.	*Mold Temp., °F.*	*Type of Graphite*
10A	2070	Mottled iron. Carbides plus nests of eutectiform graphite.
12A	2060	Gray iron. Normal flake graphite.
9A	2040	Gray iron. Normal flake graphite.
7A	1992	Gray iron. Some short flake graphite. Some eutectiform graphite in dendritic dispersion.
8A	1970	Gray iron. Eutectiform graphite in very dendritic dispersion.
13A	1955	Mottled iron. Carbides plus eutectiform graphite.
6A	1818	White iron. Traces of graphite and some temper carbon formed during cooling.

14. John Bolton[3] has published a series of observations on round cast iron bars of different diameters 6-in. long, cast in baked sand molds. Time-temperature curves of these bars show that a difference of 200°F. in the freezing temperature of a ½-in. diameter bar and a 2-in. or 3-in. diameter bar can exist, a differential similar in magnitude to that found by Schneidewind and D'-Amico.

15. Since all the foregoing experiments were made using an iron with a composition which normally would solidify gray, it is difficult to determine from them just how important a factor supercooling may be in producing white iron castings from an iron of normal malleable composition. The writer has, however, seen instances where such an iron when cast into a ⅜-in. diameter quartz tube heated to 1600°F., would always yield completely gray iron. This is rather the inverse of the experiments recorded by Schneidewind and D'Amico, and indicates that supercooling is certainly an important factor in keeping this type of iron white.

CONCLUSIONS

16. The following conclusions appear to be warranted:

(a) The inherent desire of all cast irons, determined by thermodynamic relations, is to solidify as aggregates of iron and graphite.

(b) Given sufficient opportunities of time and temperature during cooling, they will all freeze as gray iron.

(c) When they freeze as mottled or white iron, the reason is to be found in the lack of opportunity to do otherwise under the time-temperature conditions prevailing during cooling.

(d) Cast iron is susceptible to undercooling.

(e) When, by rapid cooling, this supercooling becomes about 200°F., white iron can be produced in a normally gray iron.

(f) Supercooling must be an important factor in producing white irons of malleable composition, since, when it is absent because of slow cooling, gray irons result.

Bibliography

1. Upton, G. B., *"The Habits and Laws of Decomposition of Supercooled Solutions, with Special Regard to Austenite,"* TRANSACTIONS (1939), American Society for Metals, p. 690.

2. Schneidewind, R., and D'Amico, C. O., *"The Influence of Undercooling on the Graphite Pattern of Gray Cast Iron,"* TRANSACTIONS (1939), American Foundrymen's Association, p. 831.

3. Bolton, J. W., GRAY CAST IRON, p. 222, Penton Publishing Co.

(Discussion for entire Symposium will be found on pages 133-148, inclusive.)

Graphitization Symposium—III

The Effect of Composition on the Annealing of White Cast Iron

By W. D. McMillan*, Chicago, Ill.

Abstract

Tests have been made on white cast iron ranging in silicon from 0.90 to 1.80 percent, to determine the effect of the silicon content on the length of time required to complete the first stage of graphitization. The results indicate that the time required ranges from 3 to 24 hours, depending on the silicon content. The number of temper carbon nodules also varies with the silicon content and with the length of time the iron is held at the annealing temperature.

1. This paper deals with the effect of composition, principally silicon, on the time required to complete the first stage of graphitization. The iron tested ranged in silicon from 0.90 to 1.80 percent, all of which was melted in coal-fired furnaces with the exception of iron "A" (0.90 percent silicon) which was produced in a cupola-air-furnace duplexing unit.

Composition

2. The composition of the various irons tested is shown in Table 1. Rather roughly, the silicon ranges from 0.90 to 1.80 percent. It was planned to obtain bars which represented the full range and to check the annealing characteristics at each ten points of silicon. We were unable to obtain iron with a silicon between 1.28 and 1.54 percent. For this reason, there is a spread of 0.26 percent between irons "E" and "F."

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Table 1

Compositions of Irons Tested

Iron	*Silicon, percent*	*Carbon, percent*	*Manganese, percent*	*Phosphorus, percent*	*Sulphur, percent*
A	0.89	2.76	0.37	0.108	0.149
B	1.02	2.32	0.34	0.138	0.076
B-1	1.02	2.62	0.29	0.130	0.073
C	1.10	2.76	0.30	0.150	0.069
D	1.20	2.51	0.29	0.152	0.069
E	1.28	2.44	0.31	0.126	0.066
F	1.54	2.21	0.29	0.108	0.068
G	1.60	2.31	0.32	0.086	0.072
H	1.70	2.10	0.30	0.106	0.059
H-1	1.68	2.37	0.34	0.100	0.062
I	1.79	2.30	0.34	0.112	0.067

Procedure

3. All of the iron was normally melted down to the analysis shown. It was felt that it was better to use normal iron rather than to risk the confusing and erratic results which are often found on iron to which silicon has been added in the ladle, and often times when "heavy" additions have been made to iron in the furnace.

4. The examinations were made on the ¾-in. section of a test bar, far enough from the gate to be unaffected by possible shrink at that point. All the bars under one code letter were from the same ladle and the same mold.

5. The bars were heated in an electric furnace. No effort was made to create, or hold, any special atmosphere in the furnace. The atmosphere would be considered normal for a heat treating furnace and mildly oxidizing.

6. To avoid possible variation in heat-up periods, the bars were placed in the furnace at temperature, 1700°F. The bars were removed from the furnace and allowed to cool normally in still air.

7. Completion of the first stage of anneal was established by microscopical examination as that point when all massive free cementite had been eliminated. Table 2 shows the results of this portion of the test.

8. The material tested was held at 1700°F. for different lengths of time, according to the silicon content, and specimens removed according to the schedule shown in Table 3. The irons tested were analyzed for the percent combined carbon and the percent graphitic carbon, the graphitic carbon being obtained by combustion and the combined carbon by difference. Considering the inherent de-

Table 2

TIME REQUIRED TO COMPLETE FIRST STAGE GRAPHITIZATION WITH VARYING SILICON CONTENTS

Iron	*Silicon, percent*	*Carbon, percent*	*Hours to Complete First Stage*
A	0.89	2.76	24
B	1.02	2.32	24
B-1	1.02	2.62	21
C	1.10	2.76	18
D	1.20	2.51	12
E	1.28	2.44	8
F	1.54	2.21	3
G	1.60	2.31	3
H	1.70	2.10	3
H-1	1.68	2.37	3
I	1.79	2.30	3

gree of accuracy of this determination, the results are fairly well in line and indicate that when the first stage of graphitization is complete, the combined carbon, regardless of silicon, is practically the same. The results of the determinations are summarized in Table 4.

Table 3

HOLDING TIMES FOR SPECIMENS

Iron	*Silicon, per-cent*	*Carbon, per-cent*	*Number of Hours at 1700°F.*																
A	0.89	2.76													15	18	21	24*	27
B	1.02	2.32													15	18	21	24*	27
B-1	1.02	2.62													15	18	21*	24	
C	1.10	2.76												12	15	18*	21	24	
D	1.20	2.51									9			12*	15	18	21	24	
E	1.28	2.44							7	8*	9	10	11						
F	1.54	2.21			3*	4	5	6	7										
G	1.60	2.31	1		3*		5	6	7										
H	1.70	2.10	1		3*		5	6	7										
H-1	1.68	2.37		2	3*	4	5	6											
I	1.79	2.30	1		3*		5	6	7										

MICROSCOPIC EXAMINATIONS

9. In making the microscopic examinations, it was observed that there was considerable variation in the number and size of the temper carbon nodules. Table 5 shows the graphite count for the irons of different silicon content at the point when the cementite has been completely eliminated and after several hours additional soak at the same temperature, 1700°F.

* Denotes number of hours required to complete the first stage of graphitization.

Table 4

RESULTS OF CHEMICAL ANALYSIS

	At End of First Stage		
Iron	*Average Total Carbon, percent*	*Average Graphitic Carbon, percent*	*Average Combined Carbon, percent*
G, H, H-1, I, B	2.20	1.29	0.91
E, E-1	2.48	1.52	0.96
A, B-1, C	2.61	1.71	0.90

NOTE: Iron "E-1" contained 1.28 percent silicon and 2.54 percent total carbon as cast. It was run as a check on Iron "E" and is not shown in other tables. In the above table, the irons have been grouped according to total carbon content, low, intermediate and high.

Effect of Time on Nodule Number

10. The nodule or graphite count is taken as the number discernible at x125 magnification in a single field, the figure shown in Table 5 being the average count of five fields. The change in size and number of graphite nodules with prolonged heating is clearly shown in the photomicrographs Figs. 1 and 2 of iron "D," and Figs. 3 and 4 of iron "H."

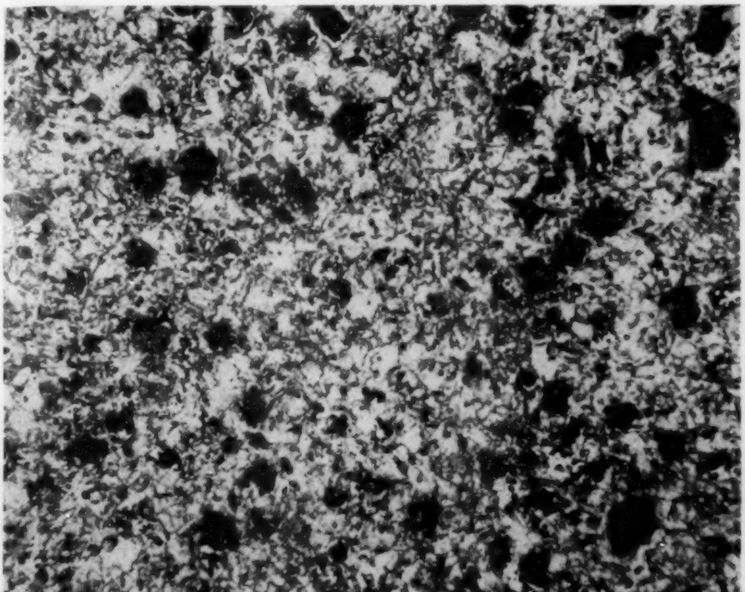

FIG. 1—IRON "D", CONTAINING 1.20 PER CENT SILICON AFTER 12 HOURS AT 1700°F. ETCHED IN NITAL, x100.

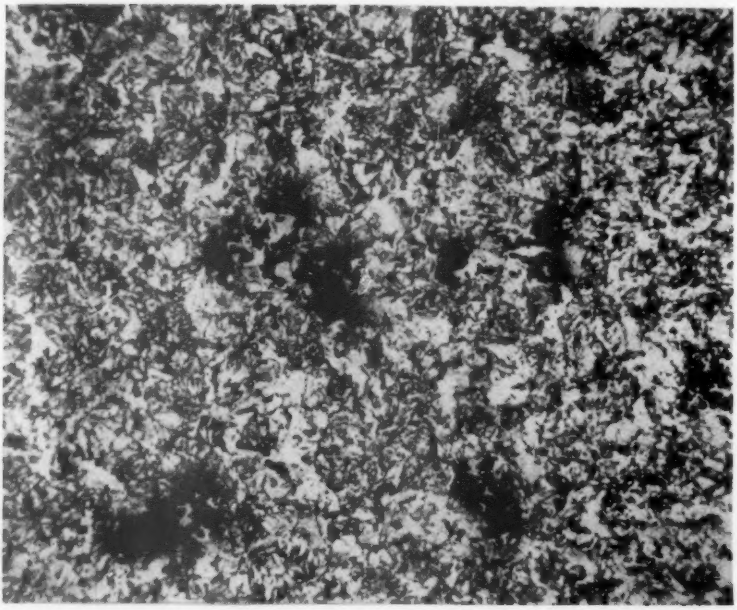

FIG. 2—SAME IRON AS FIG. 1 AFTER 24 HOURS AT 1700°F. ETCHED IN NITAL, x100.

11. The structure of iron "D" after 12 hours at 1700°F. is shown in Fig. 1, magnification x100. The structure of iron from the same bar after 24 hours at 1700°F. is shown in Fig. 2, magnification x100. Both the number and size of the temper carbon nodules have changed.

12. The same change is brought about by continued soaking of the higher silicon irons. In Fig. 3 is shown the structure of iron "H" (1.70 per cent silicon) after 3 hours at 1700°F. The magni-

Table 5

GRAPHITE NODULES IN VARIOUS SPECIMENS

			Average Number of Nodules per Field After—										
Iron	*Silicon, percent*	*Carbon, percent*	*3*	*6*	*7*	*8*	*11*	*12*	*15*	*18*	*21*	*24*	*27—Hours*
A	0.89	2.76										7	6
B	1.02	2.32										4	5
B-1	1.02	2.62							20	14	11	11	
C	1.10	2.76								36		8	
D	1.20	2.51						47				11	
E	1.28	2.44				38	32						
F	1.54	2.21	113		22								
G	1.60	2.31	120		19								
H	1.70	2.10	106		21								
H-1	1.68	2.37	99	32									
I	1.79	2.30	62		14								

fication here is x225. After 7 hours total time, or an additional 4 hours at temperature, the structure produced is shown in Fig. 4, magnification x225.

DISCUSSION

13. The results of this short series of tests have been recorded without comment, other than an effort to clarify the details of the procedure. It will be well to bear in mind that this is but one series of tests and for that reason might well be checked before any conclusions for general application are made.

14. The length of time required to complete the first stage of graphitization is specific for these test conditions. In actual practice, because of the heat up and cooling periods, the actual "hold-time" necessary would be shorter. This hold-time period, however, would, on the other hand, be increased to assure uniformity of temperature of a larger mass. Several observations have been made which may be worthy of further thought and investigation.

15. The effect of silicon is such that it requires six to eight times

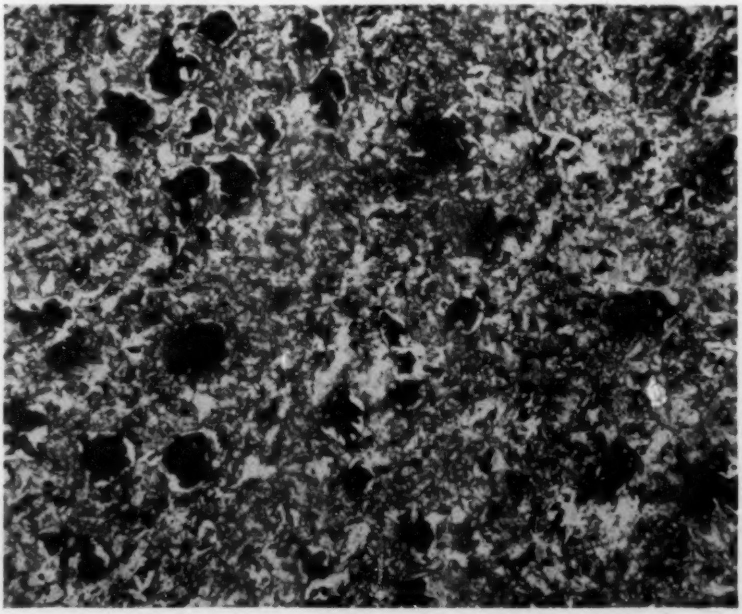

FIG. 3—IRON "H" CONTAINING 1.70 PER CENT SILICON AFTER 3 HOURS AT 1700°F. ETCHED IN NITAL, x225.

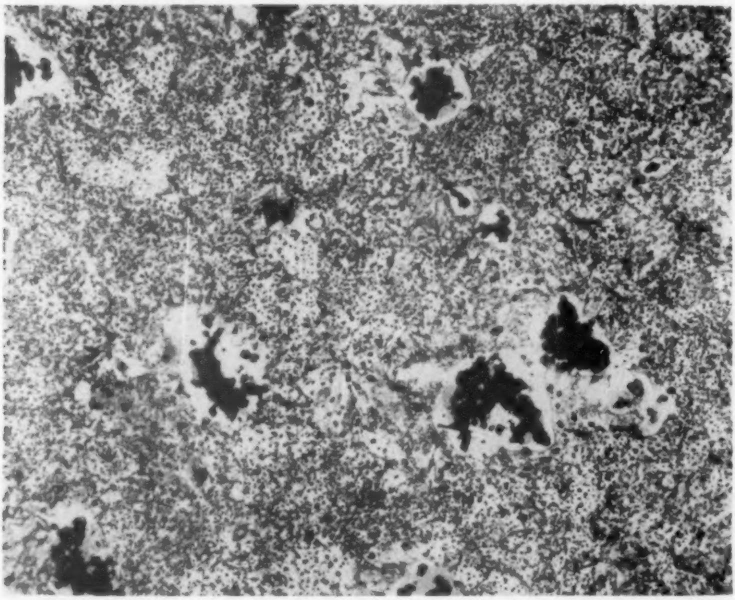

FIG. 4—SAME IRON AS FIG. 3 AFTER 7 HOURS AT 1700°F. ETCHED IN NITAL, x225.

as long to complete the first stage of graphitization with an iron containing 0.90 to 1.10 percent silicon as required for an iron with 1.54 to 1.79 percent silicon. Since iron with 1.54 percent silicon contains no cementite after 3 hours at 1700°F., it might be assumed that silicons higher than 1.54 percent were not required, at least as far as the first stage of anneal is concerned. In order to overcome factors in melting which may set up resistance to anneal, it is better not to work too close to the minimum silicon.

16. This test serves to substantiate experience that there is little or nothing to be gained from the standpoint of soaking time by using a silicon content higher than 1.70 percent.

17. With regard to temper carbon distribution, a study of the data brings out several interesting points which may perhaps be better expressed as questions for further discussion than as statements. In general, irons high in silicon ("F" to "I") show a much higher count than the lower silicon irons. Again as the higher silicon irons are heated, roughly 3 or 4 hours beyond the time required for the first stage, the count decreases markedly.

18. The graphite count on the low silicon irons is relatively low

(11 to 4) after 24 hours. This low count may be due to the length of time heated as well as to the silicon content. Iron "B" at 15 hours showed a count of only 20. On the other hand, Iron "D" (1.20 percent silicon) showed a count of 47 after 12 hours, which is a fairly high figure for low silicon iron.

19. The mechanism by which a relatively large number of small nodules is changed to a relatively small number of much larger particles by holding the iron an additional 4 hours at 1700°F., is a matter left for discussion. As an example, Iron "G" had a count of 120 after 3 hours at temperature and a count of 19 after 7 hours at temperature.

20. It is quite probable that the greater number of temper carbon nodules present in the higher silicon irons may be attributed to the higher percent of silicon. Also, that the greater number of nodules promotes graphitization, both in the first and the second stage of the anneal.

21. As prolonged heating beyond the time required tends to decrease the graphite count, the effect of longer soaking would in turn make necessary a longer cooling period.

Observation Relative to Carbon Content

22. The tests made show that the percent of combined carbon present at the end of the first stage of anneal is practically the same regardless of the silicon or carbon content as cast. Also, that when the iron is higher in carbon, the percent graphitic carbon is correspondingly higher at the end of the first stage. This would necessarily be true, since the combined carbon content is practically the same.

23. After considerable study of the data, the conclusion has been made that there are too many other factors affecting these results to permit of any statement regarding the effect of the total carbon content as cast in this series of tests.

Summary

24. It is realized that the volume of data is hardly great enough in these tests to draw any far reaching conclusions. It is quite evident, however, that the first stage of graphitization may be completed in a much shorter time with a high silicon iron (1.60 percent) than with a 1.00 percent silicon iron. The tests indicate also

that the number of graphite nodules is greater in the higher silicon irons. It is apparent, also, that with continued heating at the same temperature (and probably at a lower temperature) the number of graphite nodules decreases. There are hardly sufficient data to establish much information regarding the effect of carbon content.

25. It is hoped that readers will realize that this paper covers only one series of tests which might well be duplicated in the interest of confirmation. The observations are recorded in the hope that they may stimulate discussion and further investigation and that the information submitted may help to make an interesting and successful symposium on the graphitization of malleable iron.

ACKNOWLEDGMENTS

26. The work of W. G. Gaboda and C. A. Scherdin in helping to prepare this paper is gratefully acknowledged.

(Discussion for entire Symposium will be found on pages 133-148, inclusive.)

Graphitization Symposium—IV

Periodic Malleable Annealing Furnaces

By W. R. Bean* and W. R. Jaeschke*, Harvey, Ill.

Abstract

The direct-fired, periodic, pot type and the indirectly-fired, muffle-type ovens are the oldest of existing types of periodic malleable annealing furnaces and predominate in usage today. The most common is the floor-loaded pot type oven. In this paper, the authors explain the three general types of periodic malleable annealing ovens, giving typical layouts and illustrations of typical installations. They also discuss such subjects as oven design, comparative value of fuels, firing costs by the hand-fired, oil and pulverized-coal-fired methods, oven loading, pots and packing materials, stacking practice, temperature control, oven cycles, and methods of firing, for the floor-type pot ovens. In general, the same type of material is given for car-type, periodic, pot ovens and for the periodic, muffle-type ovens.

1. The direct-fired, periodic, pot oven and the indirectly-fired, muffle oven are the oldest of all existing types of periodic malleable annealing furnaces, and still predominate in general usage. Approximately 71.5 per cent of the malleable iron production of today is being annealed in ovens of these types.

2. Of this group, the conventional floor-loaded, pot-type oven is most commonly used. This oven is low in initial and operating costs and has for many years produced malleable iron of the highest quality. This high quality has been maintained consistently and costs steadily reduced with the application of pulverized coal and construction employing insulating fire brick. Annealing cycles,

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* Vice-President and Foundry Engineer respectively, Whiting Corporation.

Note: This paper was presented at a Malleable Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

which in the past ranged from 7 to 10 days, have been reduced to a present range of from 4 to 7 days.

3. The floor-type oven is quite simple in design. It is of rectangular box form and brick construction, suitably reinforced with steel framework. The old ovens were of heavy wall construction, of about 18-in. thickness, while the modern ovens are most generally constructed with 9-in. walls of insulating fire brick backed with several inches of primary insulation. The floors of these modern ovens also are insulated, with $7\frac{1}{2}$ to 10-in. of secondary insulating material.

4. Figure 1 shows a typical design for a modern, insulated, floor-type oven, while Fig. 2 shows an installation. At the left oven

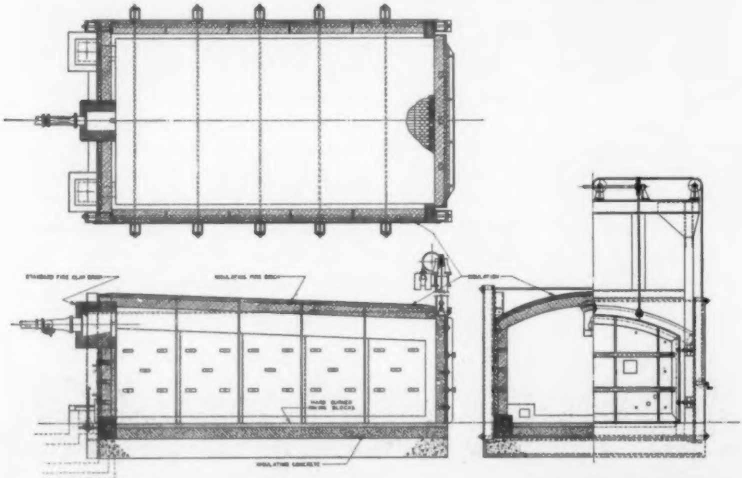

FIG. 1—TYPICAL DESIGN FOR A MODERN, INSULATED, FLOOR-TYPE OVEN.

in Fig. 2, note gas burner used for lighting and flue openings at rear of oven. Ovens of this type generally range from 20 to 40-tons capacity.

5. These ovens are generally fired from one end with pulverized coal or oil or are hand fired on a grate with lump coal. Various schemes have been in use as to flue locations, but most modern ovens are standardized with solid floor construction and with flue openings in the back wall close to the floor, the heat flowing over the top of the pots, down the spaces in front of and between the pots and along the floor to the flue outlet. Pulverized coal is the predominating fuel used to fire these ovens. Over

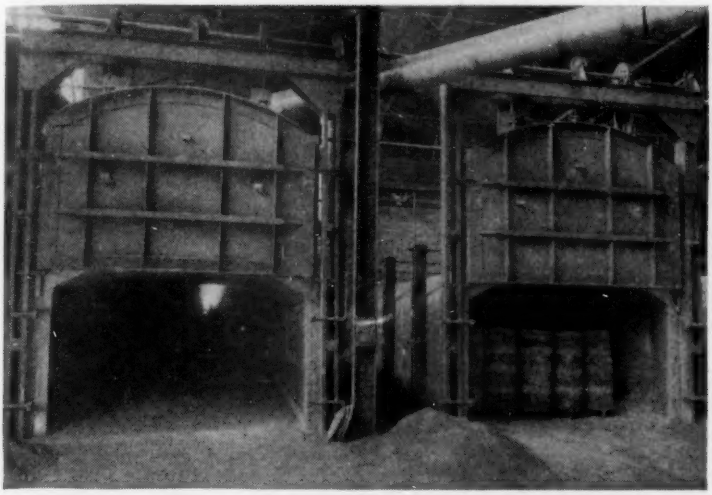

FIG. 2—TWO 32-TON CAPACITY PULVERIZED-COAL-FIRED MALLEABLE ANNEALING OVENS. NOTE GAS BURNER USED FOR LIGHTING AND FLUE OPENINGS AT REAR OF OVEN ON THE LEFT.

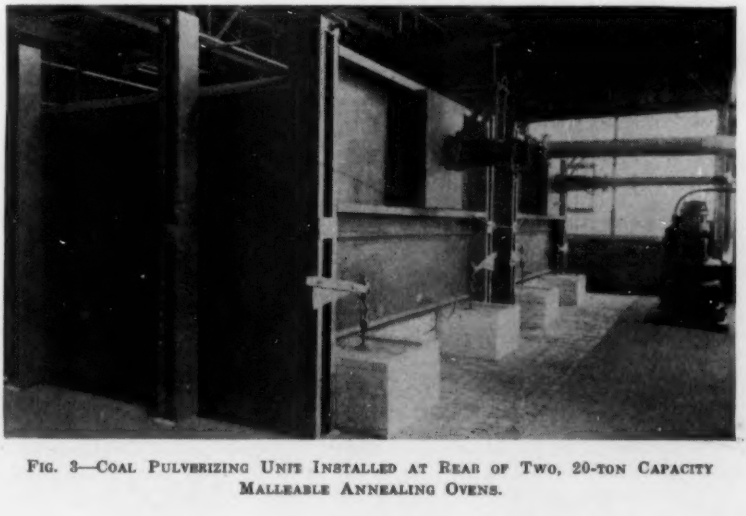

FIG. 3—COAL PULVERIZING UNIT INSTALLED AT REAR OF TWO, 20-TON CAPACITY MALLEABLE ANNEALING OVENS.

Table 1

COMPARATIVE VALUE OF FUELS ON B.T.U. PER DOLLAR BASIS

Heat Units per Dollar—(Tabulated in Thousands of B. t. u.)

Coal

B.t.u. per lb. Coal	Price Per Ton in Dollars $2.00	$3.00	$4.00	$5.00	$6.00	$7.00	$8.00
7,000	7,000	4,667	3,500	2,800	2,333	2,000	1,750
8,000	8,000	5,333	4,000	3,200	2,667	2,280	2,000
9,000	9,000	6,000	4,500	3,600	3,000	2,570	2,250
10,000	10,000	6,667	5,000	4,000	3,333	2,850	2,500
11,000	11,000	7,333	5,500	4,400	3,667	3,150	2,750
12,000	12,000	8,000	6,000	4,800	4,000	3,430	3,000
13,000	13,000	8,667	6,500	5,200	4,333	3,720	3,250
14,000	14,000	9,333	7,000	5,600	4,667	4,000	3,500
15,000	15,000	10,000	7,500	6,000	5,000	4,215	3,750

Gas

B.t.u. per cu. ft. Gas	Price Per 1,000 Cu. Ft. in Dollars $0.30	$0.40	$0.50	$0.60	$0.70	$0.80	$0.90
200	670	500	400	333	285	250	222
400	1,330	1,000	800	677	570	500	444
*550	1,815	1,375	1,100	917	786	689	622
600	2,000	1,500	1,200	1,000	857	750	666
800	2,670	2,000	1,600	1,333	1,140	1,000	888
1,000	3,330	2,500	2,000	1,667	1,430	1,250	1,110

*Denotes Municipal Gas

Oil

A.P.I.	Std. Baumel Gravity	Specific Gravity	Lb. per Gal.	B.t. per Gal.	Price Per Gallon in Dollars $0.01	$0.02	$0.03	$0.04	$0.05
No. 1	40°-42°	0.8203	6.834	136,640	13,664	6,832	4,555	3,416	2,733
No. 2	32°-36°	0.8550	7.123	139,380	13,938	6,969	4,646	3,485	2,788
No. 3	28°-32°	0.8762	7.300	141,700	14,170	7,085	4,723	3,543	2,834
No. 4	24°-26°	0.9042	7,533	144,800	14,480	7,240	4,827	3,620	2,896
No. 5	16°-20°	0.9465	7.885	149,420	14,942	7,471	4,981	3,736	2,988

A.P.I.	Std. Baumel Gravity	Specific Gravity	Lb. per Gal.	B.t.u. per Gal.	Price Per Gallon in Dollars $0.06	$0.07	$0.08	$0.09	$0.10
No. 1	40°-42°	0.8203	6.834	136,640	2,277	1,952	1,708	1,518	1,366
No. 2	32°-36°	0.8550	7.123	139,380	2,323	1,991	1,742	1,549	1,394
No. 3	28°-32°	0.8762	7.300	141,700	2,362	2,024	1,771	1,574	1,417
No. 4	24°-26°	0.9042	7.533	144,800	2,413	2,069	1,810	1,609	1,448
No. 5	16°-20°	0.9465	7.885	149,420	2,490	2,135	1,868	1,660	1,494

Electricity

B.t.u. per K.W.H.	Price Per K.W.H. in Dollars $0.0075	$0.01	$0.0125	$0.015	$0.02	$0.025	$0.03
3415	455	341.5	273	228	170	137	114

EXAMPLES: Using 14,000 B.t.u. Coal at $5.00 per ton, $1.00 purchases 5,600,000 B.t.u.'s
Using 550 B.t.u. Gas at 50c per M, $1.00 purchases 1,100,000 B.t.u.'s
Using 1,000 B.t.u. Gas at 40c per M, $1.00 purchases 2,500,000 B.t.u.'s
Using No. 3 Grade Oil at 5c per Gal., $1.00 purchases 2,834,000 B.t.u.'s
Using Electricity at 1c per K.W.H., $1.00 purchases 341,500 B.t.u.'s

NOTE:—Efficiencies, handling, maintenance and power to operate must be calculated in arriving at the net B.t.u. purchased with each fuel.

Table 2

COMPARATIVE FIRING COSTS FOR MALLEABLE ANNEALING OVENS (PERIODIC TYPE)

(Cost per Net Ton of Castings Annealed)

	Firing Method		
Cost Item	*Oil*	*Coal, Hand Firing*	*Coal, Pulverized*
Fuel Price per Unit	$0.05 per Gal.*	$5.00 per Ton (Lump Coal)	$4.50 per Ton (Screenings)
Fuel Consumption per Net Ton of Castings	75 gals.	1000 lb.	500 lb.
Fuel Cost	$3.75	$2.50	$1.13
Fuel Handling	—	0.10	0.05
Power	—	—	0.08
Maintenance	—	0.05	0.05
Labor	—	0.55	—
Total Firing Cost	$3.75	$3.20	$1.31
Possible Savings by Installation of Pulverized Coal Equipment	$2.44	$1.89	—

* Oil at $0.05 per gallon includes pumping, heating and atomizing.

65 per cent of the tonnage annealed in pot ovens comes from ovens that are pulverized coal fired. Figure 3 shows coal pulverizing unit installed at the rear of two, 20-ton capacity ovens.

6. Table 1 shows the comparative value of fuels and Table 2, the comparative firing costs for annealing ovens of the periodic type. Table 3 shows the approximate distribution of the different types of ovens and firing methods.

Methods of Oven Loading

7. Castings annealed in the floor-type or periodic pot ovens are annealed in pots either with or without packing material. The castings are placed in the pots and pots stacked one on the other. Usually 4 or 5 pots comprise a stack. All joints at the top cover, and between the pots, are sealed by luting with clay to protect the castings from the products of combustion. When the castings are surrounded by a packing material, the whole mass is practically solid and castings then are supported properly to prevent warpage. By this use of pots and packing material, the castings are assured good surface finish with minimum distortion and resultant low straightening costs.

Table 3

APPROXIMATE DISTRIBUTION OF DIFFERENT TYPE OVENS AND FIRING METHODS

Method of Firing	*Annual Casting Tonnage as of Sept. 19, 1941*	*Percentage of Capacity as of Sept. 19, 1941*		*as of Jan. 1, 1941*	
Pulverized-coal-fired	529,100		46.5		45.7
Coal, hand-fired	89,900	7.9		9.8	
Coal, stoker	27,000	2.4		2.4	
			10.3		12.2
Tunnel kiln	233,000		20.5		19.6
Oil-fired	167,450		14.7		15.4
Gas-fired	44,500		3.9		3.8
Electric	47,000		4.1		3.3
Total	1,137,950		100.0		100.0

Pots and Packing Material

8. Pots may be either round or rectangular in shape, may be of ring design or with cast in bottoms. Pots with bottoms are generally used when the castings are annealed without packing material.

9. The packing material is usually sand, gravel or crushed air furnace slag. It is important that this material be sufficiently high in refractoriness to resist fusion at annealing oven temperatures.

10. Pots should not be too large or too much time will be consumed in heating or cooling the material in the center of the pots. A pot 18-in. in one dimension inside is generally accepted as satisfactory. Pots generally average 3 to 4 cu. ft. in capacity and vary from 250 to 600 lb. each in weight. Pot life varies from 15 to 30 heats, depending on the material of construction and various service conditions.

Stacking Practice

11. The stacks should be loaded in the oven with due care to spacing, so that there is ample clearance for good circulation of the heat. The stools on which the pot stacks set should have legs high enough to permit circulation of the heat under the stacks. The oven floor should be kept reasonably free from ash for free circulation of the heat. The stacks should be spaced for a clear-

ance of 8 to 10-in. along the furnace walls and a clearance of 4-in. between the rows of pots. Round pots provide better clearances for heat circulation and can generally be set closer than rectangular pots.

12. Thermocouple provisions are generally made for taking of temperatures within the pots and also outside in the oven atmosphere, particularly so when packing material is used.

Ratio of Castings to Oven Charge

13. In pot ovens, where castings are annealed in packing material, the castings comprise about 30 to 40 per cent of the total load in the oven, pots and stools 35 to 45 per cent and packing material 25 per cent. When no packing material is used, the ratio in the load is in the order of castings 40 to 50 per cent and stools and pots 50 to 60 per cent.

14. Pots and packing material obviously create a resistance to heat penetration and are responsible for a temperature lag between the oven and that of the castings within the pots. This lag will vary from 8 to 20 hours, depending to some extent on the rate of temperature rise in the oven. Figure 4 illustrates the temperature lag in a small, floor-type oven where about 50 per cent of the castings were annealed in packing material and the other 50 per cent without packing material. Figure 5 is a typical annealing cycle for floor-type ovens annealing castings in packing material. Figure 6 is of an annealing cycle used in a floor-type oven annealing pipe fittings without packing material.

Furnace Firing

15. The firing rate of pulverized coal-fired ovens varies from 200 to 500 lb. per hour during the heating up period. During the first stage soaking period, some ovens will hold temperature as long as 20 hours without additional firing, while others may require as much as 100 lb. per hour to hold the temperature. After the first stage soaking period, the most usual practice is to open the dampers to drop the temperature to about 1400°F. Some operators force cooling during this period and reduce their cycle by several hours. From about 1400° to 1250°F., the cooling is controlled to 4 to 5°F. per hour. Whether any firing is required during this period, depends on oven size and construction.

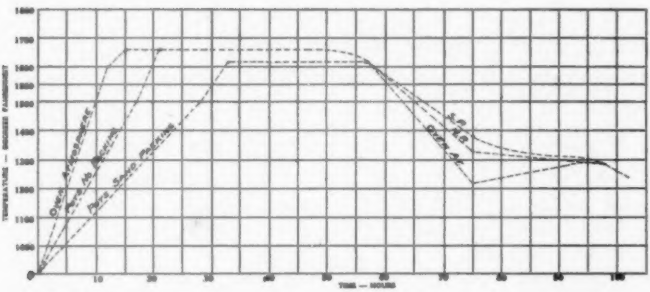

FIG. 4—TEMPERATURE LAG IN A SMALL, FLOOR-TYPE OVEN IN WHICH ABOUT 50 PER CENT OF THE CASTINGS ARE ANNEALED IN PACKING MATERIAL AND 50 PER CENT WITHOUT IT.

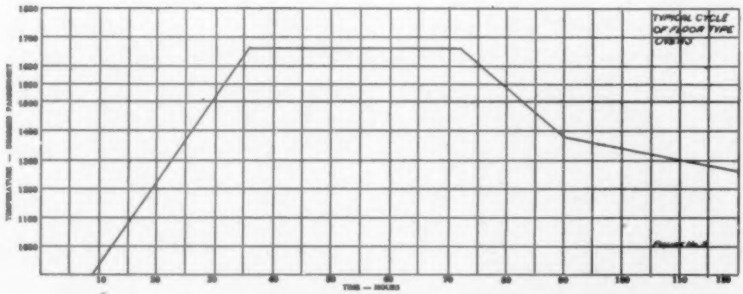

FIG. 5—TYPICAL ANNEALING CYCLE FOR FLOOR-TYPE OVENS IN WHICH CASTINGS ARE IN PACKING MATERIAL.

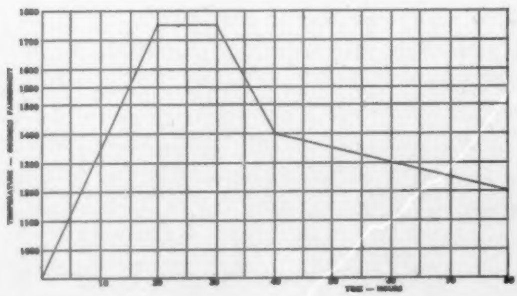

FIG. 6—TYPICAL ANNEALING CYCLE OF FLOOR-TYPE OVEN IN WHICH THE CASTINGS ARE NOT PACKED.

16. Representative costs for annealing in a 20-ton pulverized-coal-fired oven, annealing in packing material, are shown in Table 4.

Table 4

REPRESENTATIVE ANNEALING COSTS IN A 20-TON, PULVERIZED-COAL-FIRED OVEN

Cost Item	*Cost per Net Ton of Castings Annealed*
Fuel—(Coal—500 lb. at $4.50 per Net Ton)	$1.13
Labor (packing and dumping)	1.80
Pots	2.00
Fuel handling	0.05
Power	0.08
Maintenance	0.05
Depreciation	0.35
Total Cost	$5.46

CAR-TYPE PERIODIC POT OVENS

17. The car-bottom type oven is basically the same as the floor-type oven, except the floor is movable. The feature of the car-bottom permits removal of the pots from the oven at 1200°F. Rapid unloading and reloading of the car is possible so that the new charge is back in the hot furnace in time to utilize the residual heat in the furnace.

18. These ovens are generally smaller than the average floor-type oven and vary in capacity from 6 to 16-tons. Annealing

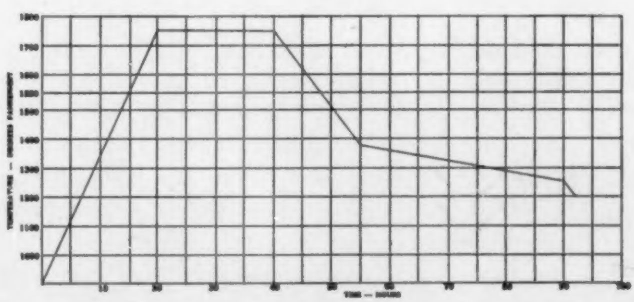

FIG. 7—ANNEALING CYCLE OF CAR-TYPE POT OVEN IN WHICH THE CASTINGS ARE NOT PACKED.

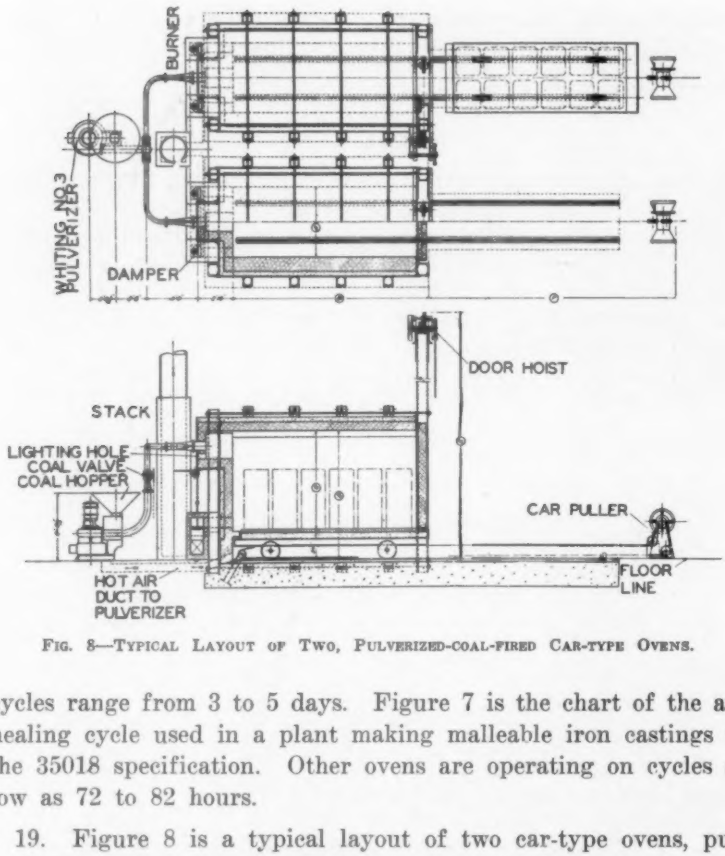

FIG. 8—TYPICAL LAYOUT OF TWO, PULVERIZED-COAL-FIRED CAR-TYPE OVENS.

cycles range from 3 to 5 days. Figure 7 is the chart of the annealing cycle used in a plant making malleable iron castings to the 35018 specification. Other ovens are operating on cycles as low as 72 to 82 hours.

19. Figure 8 is a typical layout of two car-type ovens, pulverized-coal-fired. An installation is shown in Fig. 9.

PERIODIC MUFFLE-TYPE OVENS

20. The muffle-type oven is used largely for annealing castings that lend themselves more readily to high piling or stacking rather than placing in pots. More weight can be handled per cubic foot of oven space in the muffle oven for these particular castings, than would be the case, were they placed in conventional pot ovens. A good size oven of this type can handle as high as 60 tons of castings in one charge.

21. The muffle oven is principally one brick shell within a larger one. The outer shell resembles decidedly a floor-type pot oven. Within this outer shell is the brick muffle, usually built

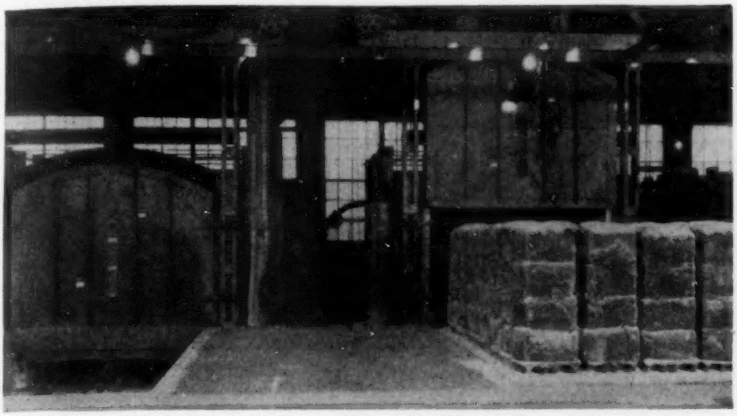

FIG. 9—INSTALLATION OF TWO, CAR-TYPE, PERIODIC, POT MALLEABLE ANNEALING OVENS.

of special refractory shapes to permit the best possible heat transfer. The inner muffle is sealed tightly against the products of combustion so no pots, nor packing material are necessary.

22. The space between the muffle and outer shell is large enough to permit proper combustion of the fuel used. Flues are so arranged as to enable the flame to heat the entire surface of the muffle.

23. The fuel used is usually oil or gas and, as in the typical floor-type oven, firing is generally from one end.

24. The annealing cycle in muffle-type ovens is longer than in either the floor-type or car-bottom-type oven. Cycles vary from 8 to 10 days.

(*Discussion for entire Symposium will be found on pages 133-148, inclusive.*)

Graphitization Symposium—V

Malleable Annealing in the Dressler or Tunnel-Type Kiln†

By R. J. Anderson*, Racine, Wis.

Abstract

The author discusses quite completely the operation, advantages and disadvantages of the tunnel-type kiln annealing furnace for malleable iron. He outlines specifically the experience of the Belle City Malleable Iron Company. He discusses in detail the choice of packing materials, construction of the kiln, methods of increasing or decreasing capacity, advantages and disadvantages of the tunnel-kiln, and methods of overcoming disadvantages. He outlines work done on his company's tunnel-kiln to increase its efficiency during times of slack operation by construction changes. He also outlines the effect of the redesign of the kiln on temperature control, how to vary the annealing cycle under the conditions outlined, and finally the cost of operation.

1. There have been a number of tunnel-type kilns built for use in both the ceramic and malleable iron industries. The manufacturers of these units include Dressler, Holcroft, and Harrup. The majority of these ovens being used in the malleable iron foundries for annealing were installed by Dressler. To the best of the author's knowledge, there are, in this country, at present, about nine Dressler tunnel-type kilns being used for annealing malleable iron castings.

2. The design of these kilns varies as to length of kiln, number of cars they accommodate, and size of cars. These variations, of course, cause a difference in the tonnage that can be loaded on each car with a resulting increase or decrease in the capacity of the kilns.

3. The temperature curve or cycle also is varied by the dif-

† In the absence of the author, this paper was presented by F. L. Harris, Belle City Malleable Iron Co., Racine, Wis.

* General Superintendent, Belle City Malleable Iron Co.

Note: This paper was presented at a Malleable Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

ferent users, depending upon the analysis of the iron to be annealed, tonnage of castings on each car, type and amount of packing used per pot, and total amount of castings to be put through each day. These differences in tonnage are taken care of by varying the number of cars pushed into, and therefore out of, the kiln each day.

4. There also are a number of different fuels used for firing, including manufactured gas, natural gas, butane, and producer gas. Thus, to maintain the relationship and to make the comparison of the various costs and processes easier, the author will confine his remarks to the kiln at the Belle City Malleable Iron Company.

5. This unit was installed and put into operation in 1924. The Dressler continuous annealing furnace is of the tunnel and car type. The castings to be annealed are loaded in pots on a train of cars that are pushed progressively through the tunnel by means of an hydraulic ram at the loading end. They are then moved along a return track outside the kiln where they are first unloaded, then reloaded and made ready for another trip through the oven. A view of this track is shown in Fig. 1. Because the kiln is full of cars, each time one is pushed in at the loading end a car is pushed out of the oven at the exit end. The pots shown are of the bottom type, and castings are packed or stacked in these pots as carefully as practical for the purpose of avoiding excessive warpage.

Packing Material

6. While it is deemed preferable to eliminate packing entirely, a percentage of jobs are found that, because of their design, must be packed. For packing material, a coarse-grained silica sand is

FIG. 1—VIEW OF TUNNEL-KILN SHOWING LOADING AND UNLOADING TRACK.

FIG. 2—ORIGINAL DESIGN OF DRESSLER KILN WITH CONTINUOUS MUFFLE ON EITHER SIDE OF THE FURNACE IN BOTH THE HEATING AND SOAKING ZONES.

used. This material is chosen for packing because it flows around the castings and packs very well in the pot. It is much cleaner to handle on the dump floor than any other material tried. The use of any active packing has not been considered because of its tendency to decarburize, with a resulting penalty in machinability.

Construction

7. The original design of the Dressler kiln had a continuous muffle on either side of the furnace in both the heating zone and in the soaking zone, as shown in Fig. 2. Combustion takes place within the specially-designed tile muffle and the hot gases are drawn from one end to the other by a fan, then through a flue to a preheater and exhausted to the atmosphere.

8. The tile which forms a double-walled chamber is shown in Fig. 3 and is so designed that the differences in temperature from the top to the bottom promote a circulation of gases which theoretically go down through the annealing pots and back around the combustion chamber for reheating as shown in Fig. 4. These tile are set on a fire brick bench on either side of the furnace and are bedded in with a layer of silica grains which allows them free movement in their expansion and contraction.

Methods of Increasing or Decreasing Capacity

9. Since the original installation of these kilns, a number of

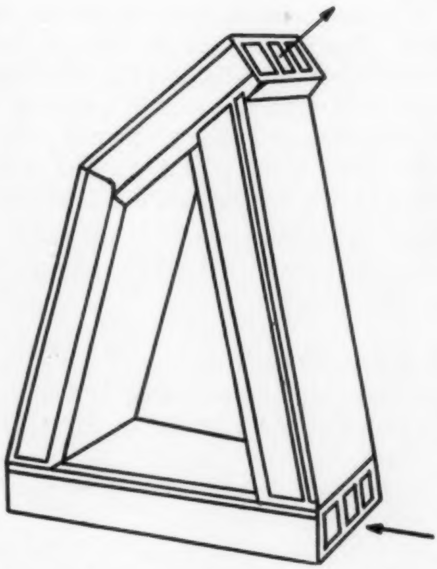

FIG. 3—SINGLE SECTION OF COMBUSTION CHAMBER. ARROWS INDICATE THE DIRECTION OF CIRCULATION.

them have been modified to meet a demand for either an increase or a decrease in annealing capacities. Increased capacity could be obtained in three different ways. First, by placing additional burners at the entrance end of the kiln to allow more B.t.u. input.

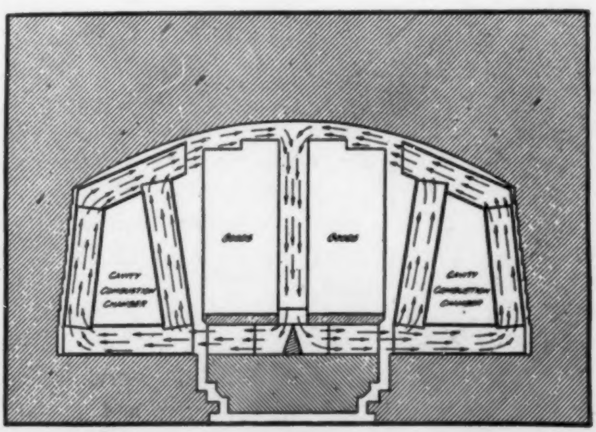

FIG. 4—DIAGRAMMATIC SKETCH SHOWING MECHANISM OF HEAT DISTRIBUTION IN HEATING ZONE.

This, of course, brings the castings up to the soaking temperature in a shorter time. Secondly, a rapid cooling zone, at the end of the soaking zone, can be applied by the use of circulating cold air to lower the temperature of the pot from the soaking temperature to 1425° to 1400°F. in as short a time as possible. Thirdly, the elimination of as much packing material as possible to reduce the total weight to be heated up to temperature and later cooled.

10. A decrease in capacity could be obtained in two ways—either by shortening the length of the kiln or by pushing fewer cars per day through the kiln.

Advantages of Tunnel-Kiln

11. It should be explained here that in the kiln at the Belle City Malleable Iron Co., there are 62 cars at all times and each car is loaded with from 4½ to 5 tons of castings to be annealed. Suppose, for example, that foundry production was 84 tons of castings per day for 5 days. At this rate, it would be necessary to anneal 420 tons per week. The kiln, of course, is operated on a 7-day per week basis, which means that 60 tons of castings or 12 cars would have to be pushed per day.

12. From this, it will be seen that the total time of the annealing cycle with a 12-car push per day would be 124 hours. Generally speaking, this affords very satisfactory delivery of castings to the customer because the only time it would be advantageous to have a shorter anneal than this would be the first few days' run on a production lot of castings. For example, suppose a particular job is put into production in the foundry on a certain day. Five days later castings will be out of the annealing oven and available for shipment after cleaning and finishing. Also, there will be castings available for shipment each day thereafter as long as the foundry maintains its production. This, together with the advantages of having a uniform or continuous amount of tonnage passing through the cleaning and finishing departments at all times and the continuous supply of pots for the chippers, is decidedly in favor of the tunnel-type kilns.

Disadvantages of Tunnel-Kiln

13. However, these conditions do not hold true during a low production or depression period, such as we had during 1930 to 1935. The advantages pointed out above are partly lost to a plant like this with only one kiln in operation. For instance, suppos-

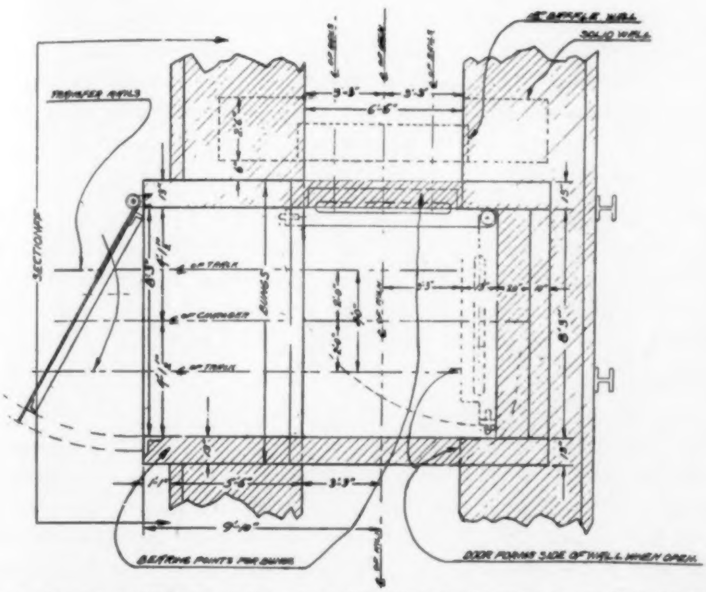

FIG. 5—DESIGN OF OPENING AT CENTER OF KILN USED TO SHORTEN IT FOR LOW CAPACITY OPERATION.

ing the daily production drops to 35 tons of castings per day. Unless we push dummy cars or cars of sand so that we can maintain a high car push per day, only about 5 cars could be pushed, and the result would be an annealing cycle of almost 12½ days. This would result in delivery that would not be satisfactory to a customer. The continuation of available castings out of the oven would also be affected because during periods of this kind, in addition to the reduction in production, there is also a reduction in the quantity of castings ordered at one time. It was found that, both from the delivery and economical standpoint, the kiln could not be operated justifiably at lower than a 6-car push per day.

Overcoming Disadvantages

14. To overcome the disadvantages encountered during these low production periods, a third opening was made in 1938, in the center of the oven as shown in Fig. 5. By the use of a hinged swinging door, and operated by air from the outside of the oven, the door can either be swung to the closed position where it forms part of the side wall of the 62-car kiln, or, during a low production period, can be used in the open position to serve

as the exit of the 31-car kiln. The same type transfer pit and transfer car are used in this center section as are used on either end. The transfer car is used as such when operating the 31-car kiln and is left in place to form that part of the floor in the oven when using the 62-car kiln. The outside door and chamber also are the same as used on the ends.

15. This change resulted in a flexible unit that could be operated fairly economically at a low car push and enabled the plant to make satisfactory delivery to its customers. The short kiln was operated under these conditions for a period of about one year and the pushes per day were varied from 4 to 7 cars.

Operation of Revised Kiln

16. To properly zone the heat curve of the 31-car kiln, it was, of course, found necessary to add burners at the front or entrance end of the kiln. This was done by using proper burners and proportional mixers. Twelve of these burners were installed on each side and were fed through two manifolds, each manifold caring for 6 burners. A cross section of the kiln at this point is shown in Fig. 6, and the arrangement of these burners and manifolds is shown in Fig. 7.

17. The results of this were two-fold: First, it was possible to properly zone the 31-car kiln so as to maintain the proper time-temperature cycle for a 4 to a 7 or 8-car push per day. Secondly, it gave a rapid heating zone at the entrance end of the kiln that should increase the capacity considerably. An opportunity has not presented itself, as yet, to go beyond an 11-car push per day, but it seems reasonable to expect that, with the additional B.t.u. input at the head end, it should be possible to get at least 14 cars per day.

18. Figure 8 shows a time-temperature curve on a 6-car push with the original oven and a 6-car push with the 31-car oven. You will notice here that there is a difference of 115 hours in the complete cycle, the 62-car oven requiring 240 hours for a complete cycle. This, as we mentioned before, is the reason for the impracticability of tunnel-type kilns when production drops off. Figure 9 is another time-temperature curve showing the difference between a 10-car push curve in the original and redesigned kiln. You will notice that the total time is exactly the same because the 62-car kiln was used in both cases. However, the rapid heating

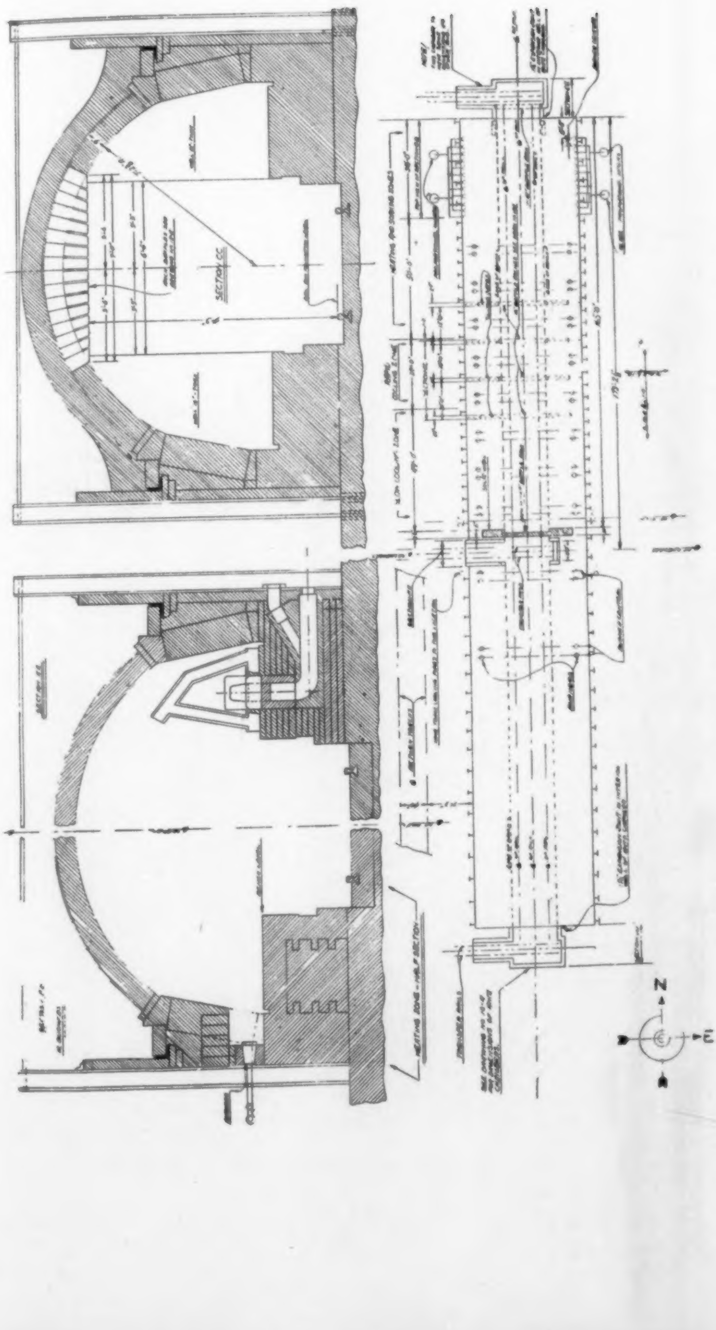

Fig. 6—Cross Section of Redesigned Heating Zone of Shortened Kiln.

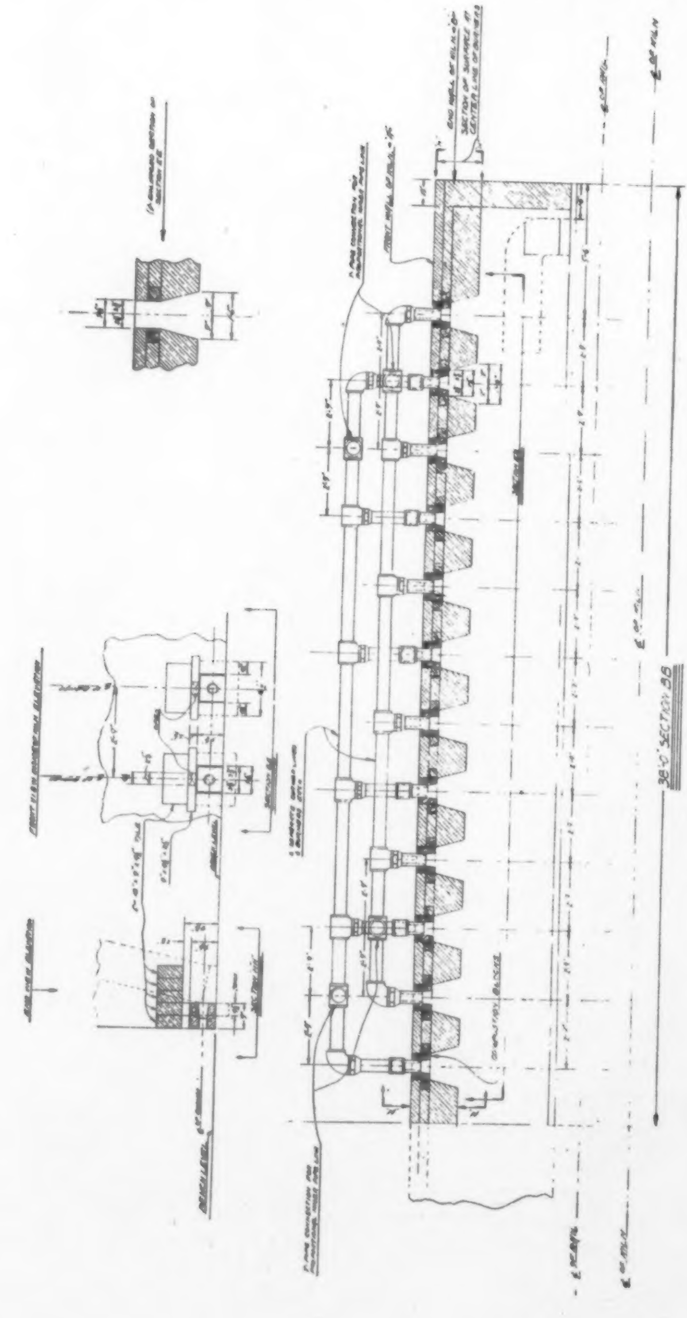

FIG. 7—ARRANGEMENT OF BURNERS IN SHORTENED KILN.

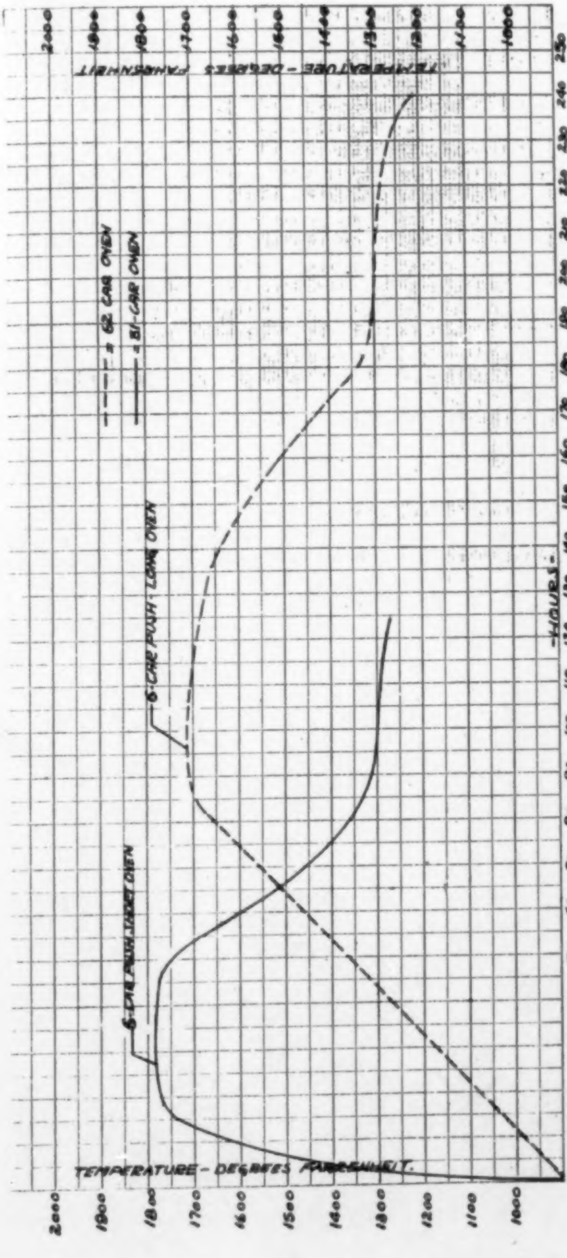

FIG. 8—TIME-TEMPERATURE CURVE ON 6-CAR PUSH WITH ORIGINAL OVEN COMPARED WITH SAME TYPE CURVE FOR SHORTENED OVEN.

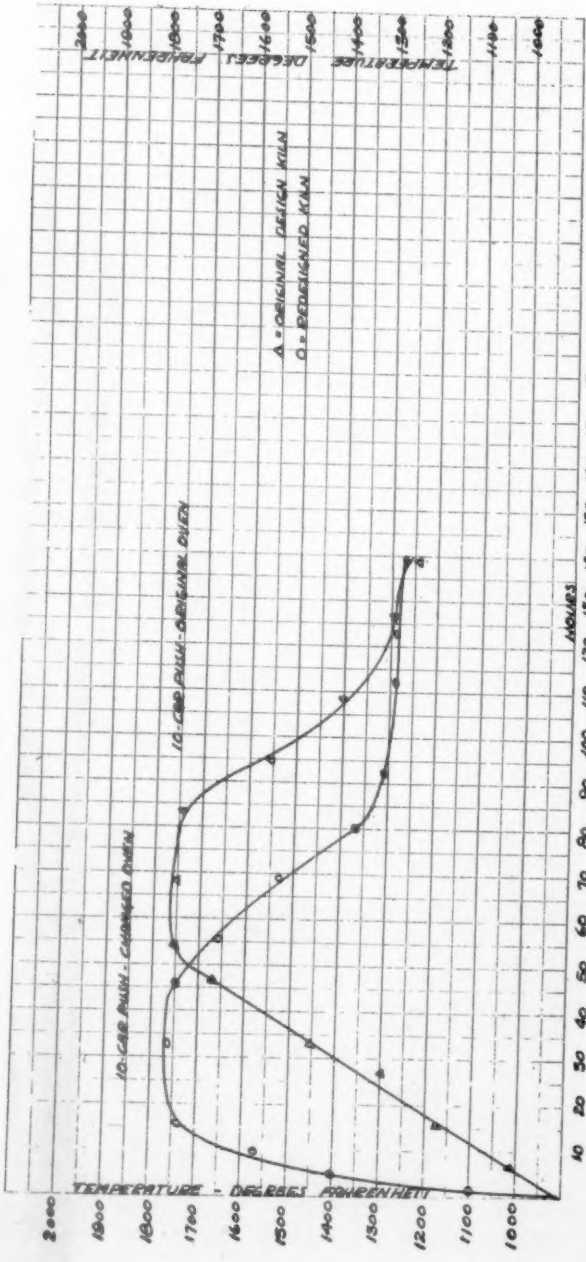

FIG. 9—COMPARISON OF TIME-TEMPERATURE CURVES FOR 10-CAR PUSH IN ORIGINAL AND REDESIGNED KILNS.

zone shows a definite advantage in that a much longer period is allowed for secondary graphitization. You will also notice that there are approximately 30 hours saved in the heating time.

Effect of Redesign on Temperature Control

19. One would expect a considerable lag between the temperature of the castings in the pot and the thermocouples in the arch. To determine this, tests were run, placing a thermocouple inside of the top and bottom pots and running them through the kiln. These curves are shown on chart, Fig. 10, and you will notice that there is a difference of 50° to 100°F. from the beginning of the cycle to the end of the soaking zone. At this point, the lines come very close together and the control to and through the second stage graphitization period is very uniform and corresponds quite well with the different temperatures of the thermocouples as read in the control room. However, in the soaking zone, more time is required for soaking and a higher temperature is required to make sure that the bottom pot gets the proper time and temperature for first stage graphitization. This, of course, is simple to figure after the variables are known.

20. All of the plant's annealing cycles are based on the idea of getting up to the soaking temperature as rapidly as possible. This is accomplished, as you see on some of the charts, in from 15

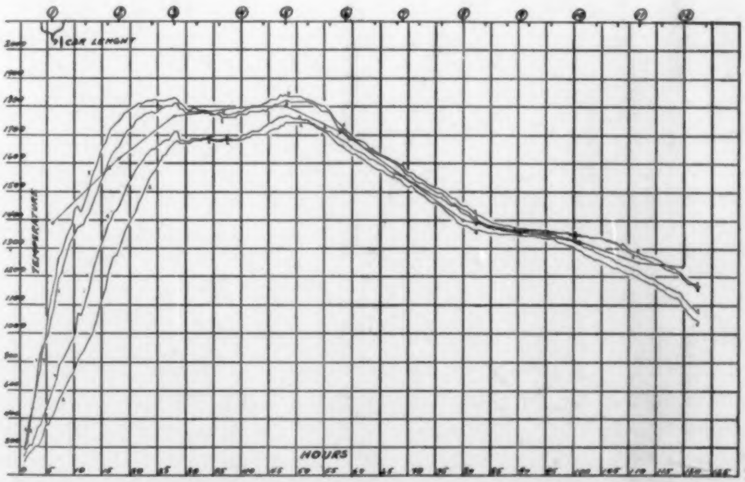

FIG. 10—TIME-TEMPERATURE CURVES OF TEMPERATURES REGISTERED IN POTS AND IN THE ARCH OF REDESIGNED KILN DURING OPERATION.

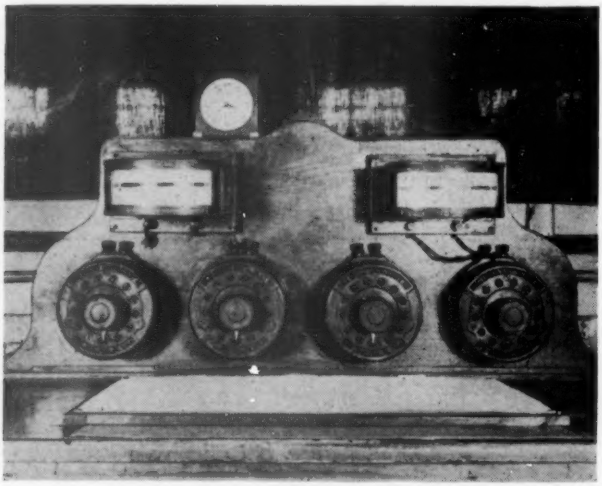

FIG. 11—VIEW OF PYROMETER CONTROL PANEL.

to 20 hours. The charge then is held long enough to be sure of first stage graphitization, which is determined by micro-examination of sample castings taken from the cycle in question. In this particular case, this has been from 25 to 35 hours. The charge is then cooled as rapidly as possible to 1400° to 1425°F., either by use of circulating air in the muffle chambers at the proper point or by removing insulating material from the roof of the kiln at this point. From 1400° to 1300°F., a drop of about 5 degrees per hour is maintained. At 1320°F., the charge is held for a period depending upon the time available. This, of course, is controlled by the number of cars being pushed. This general type of cycle has given a satisfactory and uniformly malleable product which conforms to the standard A.S.T.M. 35018 specification with an average of 53,000 to 57,000 lb. per sq. in. tensile strength and a large percentage of our wedges testing at 30 blows.

Methods of Varying Annealing Cycle

21. The temperature curves are easily varied within reasonable limits to suit the car cycle required. That is, the heating and soaking zones can be moved toward the front of the kiln to allow the maximum number of cars to be pushed per day and still leave enough time for second stage graphitization. The curve can be flattened out by moving these zones toward the center, still allowing plenty

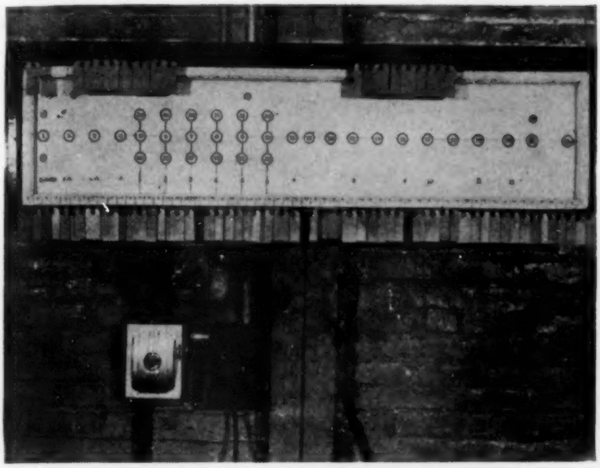

FIG. 12—VIEW OF PRODUCTION BOARD.

of time for second stage graphitization and maintaining the same exit temperature.

22. Experience has taught that it is better to lay out the time-temperature curves by starting from the cooling or exit end of the oven and working back to the heating zone. In this way, sufficient time is allowed for second stage graphitization, with either an increase or decrease of level for heating to temperature and cooling

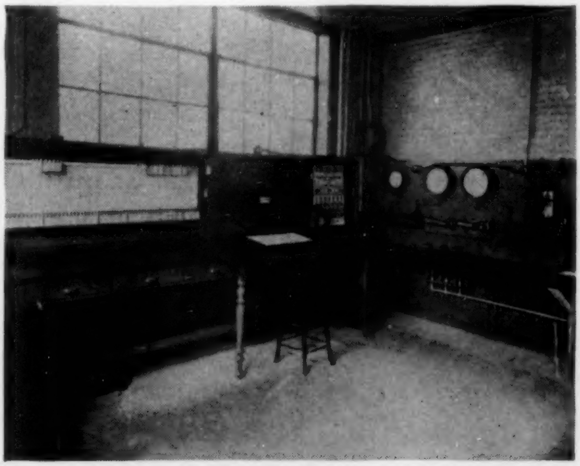

FIG. 13—VIEW OF ANNEALING CONTROL ROOM.

to 1425°F. The reasons for this are purely to effect economies. We have found very little, if any, difference in quality due to fast or slow heating, but of course have found considerable difference if the cooling rate is varied from 1400°F. to 1300°F.

Controlling Kiln Temperatures

23. After a cycle has been established, it is closely maintained by the use of 34 thermocouples placed in various positions in the arch of the oven. All of these are connected to the pyrometers in the control room, as shown in Fig. 11, and by means of rotary switches, can be read one at a time. Readings at each thermocouple are taken each hour, and any variation in temperature is immediately corrected by the adjustment of burners in that particular part of the kiln. The production board, Fig. 12, has each thermocouple indicated by a circle, and a sliding hook arrangement representing each car, inside and outside of the oven. The tags are marked to indicate the type of casting, rush jobs, etc. on each car. Fig. 13 is a view of the control room.

Costs

24. To give an accurate comparison of costs between the oven fired with 520 B.t.u. gas and butane is difficult because the plant's experience has not been over a long enough period of time.

25. In Table 1, it will be noted that some changes have been made that would affect the cost. For instance, the section of the wall in the pot was changed, not to reduce the weight, but to strengthen the corners of the pot to eliminate distortion. It also will be noted that there is quite a difference in the therms per ton used in the short oven as compared to the original oven using 520 B.t.u. gas. And also the pot cost per ton is up on the short oven with butane. A lot of trials and experiments have to be made to find out exactly how to burn this fuel and how to properly adjust the burners. The author believes it is fair to assume that after standard operating schedules for all the different cycles have been set up, a 40 to 45 therm per ton fuel consumption will be reached, and that pot cost will be comparable to the $2.34 cost which was possible on the original oven. To substantiate this, during the past month, pot life has been increased by approximately 30 per cent due primarily to a change in the method of firing. However, the first two rows of figures on the original oven, fired with 520 B.t.u. gas, are accurate and were determined over a period of years.

Table 1

ANNEALING COSTS IN A DRESSLER KILN

Type Oven Used	*Type Fuel Used*	*Number of Cars Per Day*	*Pounds Castings Per Pot*	*Number of Heats Per Pot*	*Therms Used Per Ton*	*Fuel Cost Per Therm*	*Fuel Cost Per Ton of Castings*	*Pot Cost Per Ton of Castings*	*Labor* Cost Per Ton of Castings*	*Misc. Cost Per Ton*	*Tons Castings Annealed Per Month*	*Total Cost Per Ton*
Original	Mfg'r. Gas	11	385	46	39.50	0.0583	2.30	2.34	1.95	0.11	1450	6.70
62-Car	520 B.t.u.			¾" Wall								
Oven	Per Cu. Ft.											
Original	Mfg'r. Gas	4½	385	46	67.60	0.06	4.05	2.34	2.50	0.11	590	9.00
62-Car	520 B.t.u.			¾" Wall								
Oven	Per Cu. Ft.											
Changed	Butane	5	385	30	53.00	0.047	2.49	3.53	2.45	0.11	620	8.58
31-Car	102,000 B.t.u.			½" Wall								
Oven	Per Gal.											

* NOTE: "Labor" includes ovenmen, cranemen, chainers, mudders, dumpers, and miscellaneous.

26. Please note the difference in fuel cost between the 11-car push and the 4½-car push. The author brings this out because of its importance to anyone considering tunnel-type annealing and with a production that would not allow the oven to operate at near full capacity all the time. As previously stated, the author expects that the short oven will finally give a total annealing cost somewhere in the neighborhood of the $6.70 cost obtained on the original oven. This will afford a very flexible and economical means of annealing.

Conclusion

27. In conclusion, the author might say that the advantages of the tunnel-type kiln, with its low refractory cost, comparatively good furnace efficiency, excellent uniformity and control plus the assurance of a steady flow of production through the cleaning and finishing departments and the advantage to the customer of having castings available each day, are decidedly in its favor. The only real disadvantage that has been found is the fact that when production dropped below 600 tons per month, quite a penalty was exacted in fuel cost and too great a delay in delivery of the first castings of an order to the customer because of the long period of time required to go through the regular kiln at a 4 to 6-car push.

(*Discussion for entire Symposium will be found on pages 133-148, inclusive.*)

Graphitization Symposium—VI

Electric Furnace Annealing of Malleable Iron

By R. M. Cherry*, Schenectady, N. Y.

Abstract

As indicated by the title, the author discusses two general types of furnaces, the continuous and batch types. Of the continuous-types, he outlines the construction, operation, advantages and disadvantages of the roller-hearth and pusher-tray type continuous furnaces. He also gives the same information on a continuous-type furnace, part of which is heated with gas and the remainder by electricity. Under batch-type furnaces, he discusses in detail the elevator-type electric annealing furnace, giving illustrations of various installations. He closes his paper with the discussion of some of the advantages of electric malleable annealing furnaces.

1. There are several types of batch and continuous furnaces used today for the annealing of malleable iron. The selection of the proper type and size of furnace for a particular application requires careful study of the conditions to be met and economics of the various types of furnaces that may be applicable.

2. To justify a continuous-type furnace, there must be sufficient production to keep such a furnace in continuous and full load production for long periods of time. A continuous-type furnace may become a "white elephant" to a foundry if such a furnace must be operated with frequent shutdowns, or at partial production due to lack of uniform flow of production.

3. In general, the selection of furnaces for typical foundries should be either one or more continuous-type furnaces, supplemented by a batch-type furnace or possibly all batch-type furnaces for foundries of lower production.

4. All of the types of electric furnaces discussed in this paper

* Industrial Department, General Electric Co.

Note: This paper was presented at a Malleable Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

are for use with a protective atmosphere, thereby eliminating the necessity of packing material.

CONTINUOUS-TYPE ELECTRIC FURNACES

5. Where the production warrants a continuous-type furnace, there are two types of furnaces to be considered, the roller-hearth furnace and the pusher-tray furnace.

6. For both type furnaces, the castings to be annealed are loaded in alloy trays and these loaded trays are conveyed continuously through the furnace.

7. In the roller-hearth furnace, the loaded trays are moved continuously through the furnace by means of a driven roll table. The furnace rolls extend through the furnace walls to self-aligning bearings and are driven by sprockets and chains.

8. In a pusher-tray furnace, the loaded trays are intermittently moved one tray length at a time by means of a pusher mechanism. The loaded trays usually are supported in the furnace by means of roller rails made of cast alloy having metal-to-metal bearings or the rollers may be mounted on the bottom of the trays.

9. Both of the continuous-type furnaces have their uses but in the majority of cases, the roller-hearth furnace has certain advantages that warrant its selection over the pusher-tray furnace.

Comparison of Roller-hearth and Pusher-tray Furnaces

10. For the same production and annealing cycle, the first cost of the roller-hearth furnace is usually more than that of the pusher-tray furnace but this difference is partially offset by the lower first cost of the trays required for the roller-hearth furnace. The trays in the roller-hearth furnace can be made much lighter since they are required to support only the loads on the trays, while the tray in the pusher-tray furnace must be of sufficiently heavy design to take the push of the entire load, in addition to carrying its own load of castings. In general, the efficiency or economy of operation (*i.e.*, k.w.h. per net ton of castings annealed) is, if anything, slightly in favor of the roller-hearth furnace.

11. Other advantages of the roller-hearth furnace as compared to the pusher-tray furnace are: Lower maintenance cost, particularly on the trays and roller rails, and the ease with which the furnace can be cleared of work when a shutdown is desired. In the

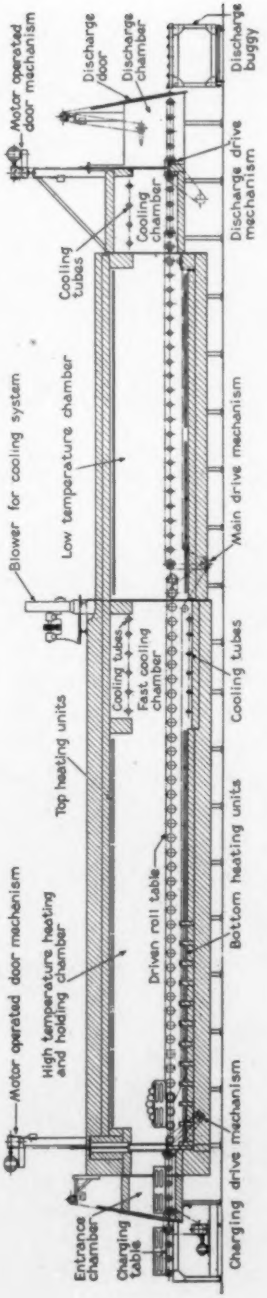

FIG. 1—LAYOUT OF TYPICAL ELECTRIC, ROLLER-HEARTH MALLEABLE ANNEALING FURNACE.

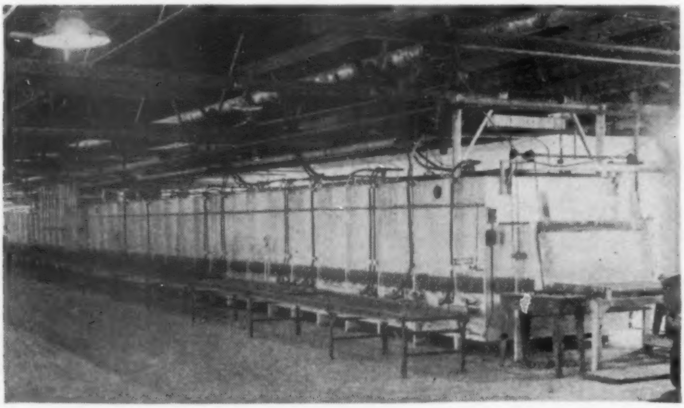

FIG. 2—ELECTRIC, ROLLER-HEARTH, ANNEALING FURNACE SHOWING CHARGING END AND TRAY-RETURN CONVEYOR. THIS FURNACE IS 62-IN. WIDE, 28-IN. HIGH AND 120 FT. LONG.

case of a pusher-tray furnace, empty trays, and in case of a long furnace, trays filled with scrap load, must be loaded into the furnace to push out the good castings before shutting down.

12. The roller-hearth furnace is limited as to its width, due to the strength of the rolls, but such a furnace can be made of any length. The pusher furnace is not limited in its width as several parallel rows of trays may be pushed through the furnace but such a furnace is limited in length as the longer the furnace, the greater the push that must be taken by the trays.

OPERATION OF ROLLER-HEARTH FURNACES

13. A typical electric, roller-hearth furnace is shown in outline in Fig. 1 and an installation of such a furnace is shown in Figs. 2 and 3. The furnace shown in Figs. 2 and 3 has an inside wall to wall width of 62-in. and overall length of approximately 129 ft. over loading and discharge tables.

14. The castings are loaded in trays having overall dimensions of 27x27-in. and the net loading averages about 475 lb. net per tray. The production varies from 32 to 35 net tons per 24 hour day, depending on the loading per tray. The total annealing cycle is approximately 15 hours, as the iron being annealed is a high silicon iron. The energy consumption is approximately 267 k.w.h. per net ton of castings annealed.

Sequence of Operations

15. The sequence of operation of this roller-hearth furnace is as follows: Two loaded trays are placed in the loading position on the roll table in front of the furnace, there being two rows of trays in the width of the furnace. When the trays are in position, the operator raises the door to the entrance chamber of the furnace and pushes the two trays into the entrance chamber and closes the front door. When the trays in the main heating chamber have advanced one tray length, thereby providing room for a charging of the new tray, then automatically, as controlled by limit switch, the door between the entrance chamber and the main heating chamber is automatically opened and the two trays in the entrance chamber are automatically rolled into the heating chamber and the door closes.

16. As the trays near the discharge door of the cooling chamber, they contact a limit switch and automatically the door at the end of the cooling chamber is opened and a separate drive mechanism picks up to overdrive the last few rolls in the cooling chamber and rolls the last tray in each row out into the discharge chamber quickly. There the trays are stopped and the door at the end of the cooling chamber is closed. The operator then opens the door of the discharge chamber and pulls out the trays on the discharge table or the trays may be automatically discharged. With

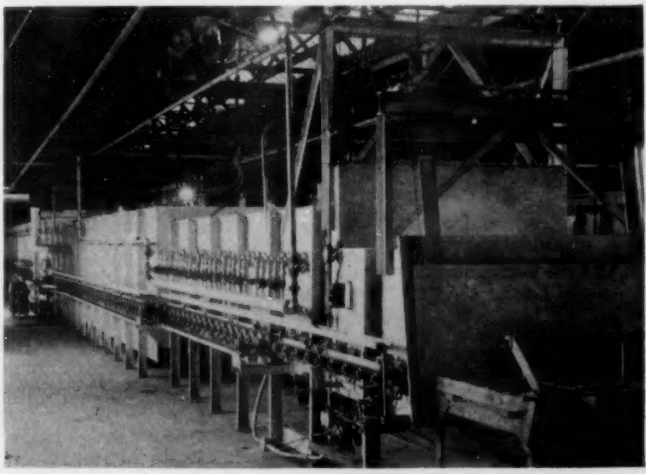

FIG. 3—SAME FURNACE AS FIG. 2, SHOWING DISCHARGE END.

this scheme of operation, the furnace chamber proper is never opened to the outside atmosphere.

17. When the tray has been emptied, the discharge table is pushed over in front of the return gravity roll table and the empty tray is pushed off onto this return roll table and thereby returned to the loading end of the furnace. Usually the castings are loaded while the trays are on the return gravity roll table and then the loaded tray is picked up by a monorail hoist and placed in loading position at the front of the furnace.

Furnace Construction

18. The length of the furnace is divided into four main sections. First, the high temperature section where the castings are heated to the required temperature, say 1750°F., and held at that temperature for the required number of hours. The second section is the fast-cool section where the castings are quickly cooled from the high temperature to the required low temperature portion of the cycle.

19. This cooling is accomplished by cooling tubes located above and below the loaded trays. These tubes are made of heat-resisting alloy and extend through the walls of the furnace, one end of each tube being connected to a common header to which is connected a motor-driven blower. This blower forces air through the cooling tubes and the cooling is automatically controlled by means of a thermocouple operating in conjunction with the standard type of temperature control instrument and control panel which throws the motor blower on and off to control the cooling.

20. The third section is the holding or slow-cool section of the low-temperature portion of the cycle. This usually is followed by another fast-cool section for cooling the castings to some lower temperature before they are discharged from the furnace. In this last fast-cool section, the cooling is normally accomplished by means of water-cooling tubes located in the top of the furnace.

CONTINUOUS-TYPE GAS-ELECTRIC FURNACE

21. For those locations where natural gas is available at low rate, a combination gas-electric, roller-hearth furnace is available. Such a furnace takes advantage of low-cost fuel to supply the bulk of the heat required for heating the cold castings in the beginning; then takes advantage of the use of electric heat for the control of

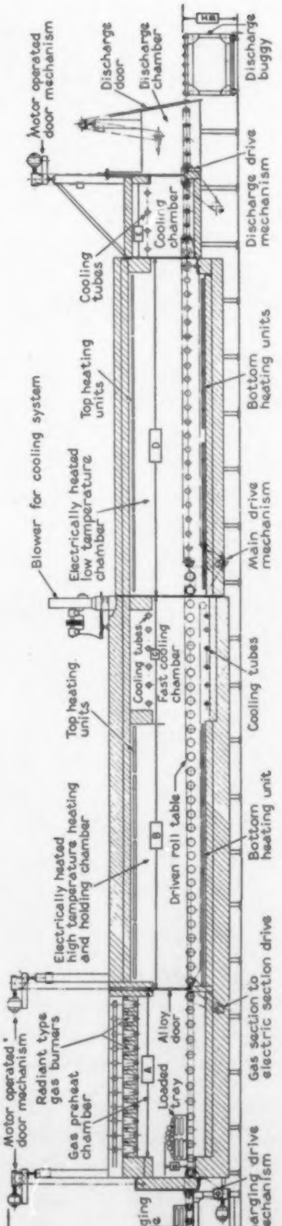

FIG. 4—LAYOUT OF TYPICAL GAS-ELECTRIC, ROLLER-HEARTH, MALLEABLE ANNEALING FURNACE.

the holding and slow cooling portions of the annealing cycles.

22. Such a furnace is shown in outline in Fig. 4. This is the same construction as the all-electric furnace, except the entrance chamber now becomes a gas-heated chamber.

23. The loaded trays are heated to approximately 1300 to 1400°F. in this gas-heated chamber, then they are automatically transferred into the electrically-heated section. The burners are of the radiant type, located in the top of the furnace. The products of combustion are passed down through the charge. The air and gas are pre-mixed. Therefore, the gas is burned under controlled conditions.

24. Table 1 shows the estimated energy required for various production and annealing cycles and for both the all-electric and the combination gas-electric furnaces. The data given in Table 1 are the estimated economies of an all-electric and a gas-electric roller-hearth furnace. All estimates are based on a furnace having inside wall to wall dimensions of 62-in. and loading 475 lb. net on trays 27x27-in., trays weighing 150 lb. each.

Table 1

ENERGY CONSUMPTION OF ALL-ELECTRIC AND GAS-ELECTRIC MALLEABLE ANNEALING FURNACES

Furnace No.	*Tons Production per 24 hours*	*Total Annealing Cycle, hours*	*All-Electric, K.W.H. Per Net Ton*	*Gas-Electric, Per Net Ton*	
				K.W.H.	*1000 B.t.u. Gas for Preheating, cu. ft.*
1	35	15	267	110	840
2	25	15	290	128	865
3	15	15	300	137	875
4	35	30	420	260	840
5	25	30	440	280	865
6	15	30	450	295	875
7	25	45	520	360	865
8	15	45	535	375	875

BATCH-TYPE FURNACES

25. There are several batch-type, electric furnaces, but one in particular has been used very successfully in annealing malleable iron. That is the elevator-type furnace. The elevator-type furnace is a car-type furnace where the charge is loaded on the car and then the charge is elevated into the furnace, the car being sealed with the bottom of the furnace.

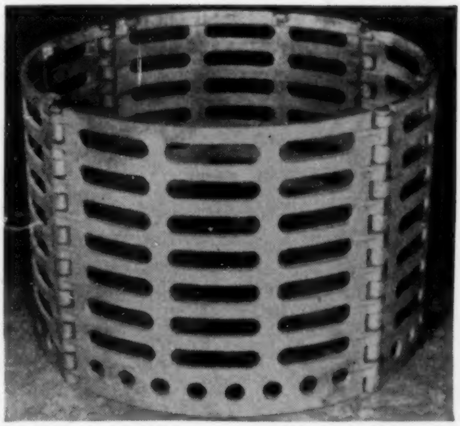

FIG. 5—HEAT RESISTING ALLOY CONTAINER FOR MALLEABLE CASTINGS. INSIDE DIMENSIONS: 24½-IN. DIAMETER, 16⅜-IN. DEEP.

26. Such a furnace has its steel casing welded gas-tight and the terminal bushings are provided with gas-tight stuffing boxes, thereby making an exceedingly tight furnace that requires little or no outside source of protective atmosphere.

27. In such furnaces, the castings are loaded in light-weight containers. One design of such container, shown in Fig. 5, is round and made of an assembly of alloy castings. These containers may be stacked two or three high and, in that case, a suitable cast alloy grid support is provided between the containers.

28. The loaded containers are placed on the raised alloy platform of the car which elevates the charge above the brickwork of the car to such a point that it permits uniform heating of the bottom of the charge.

Types of Batch-type Furnaces

29. The furnace may be of the single chamber type or there may be two separate chambers adjacent to each other, depending on the production and the annealing cycle required.

30. For the annealing of the usual malleable iron and using a single chamber furnace, the entire cycle is carried out in the one chamber. This furnace is provided with auxiliary cooling equipment so as to cool down the charge in the furnace from the high temperature portion of the cycle to the lower portion of the cycle.

Elevator-type Furnaces

31. The more economical layout is the use of two such furnaces, located adjacent to each other, where one of the furnaces is used for the high temperature portion of the cycle and the other chamber is used for the low temperature portion.

32. In such an installation, at the completion of the heating and holding time in the high-temperature furnace, the charge is removed from that furnace and immediately placed in the low-temperature furnace where the charge then is cooled quickly by an auxiliary cooling system mounted in the roof of the low-temperature furnace. This fast cooling is carried to a point that is desired and then the charge is held at the required temperature or slow-cooled for that low-temperature portion of the cycle.

33. Figure 6 shows three furnaces of an installation of 8 elevator-type furnaces used for the annealing of malleable iron. Some of these furnaces are used for the high temperature portion of the cycle and then, after the completion of that holding period, the charge is withdrawn from the furnace onto a transfer car, moved, and placed into one of the low-temperature furnaces. These eight furnaces have loading dimensions of 4 ft. wide; 12 ft. long and 3½ ft. high. The net weight of castings per charge varies from 4 to 8 tons, depending on the castings. The iron being annealed has a silicon content of 0.90 to 1.00 percent and the annealing cycle

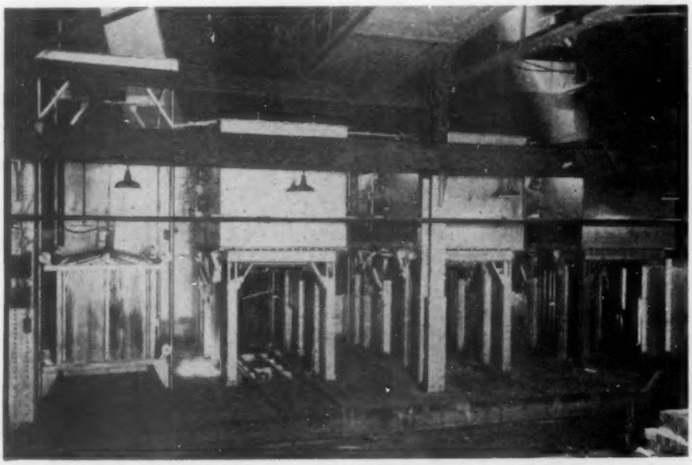

FIG. 6—THREE OF AN INSTALLATION OF EIGHT ELEVATOR-TYPE, BATCH-TYPE, ELECTRIC, MALLEABLE ANNEALING FURNACES USED FOR PRODUCING SHORT-CYCLE MALLEABLE IRON CASTINGS.

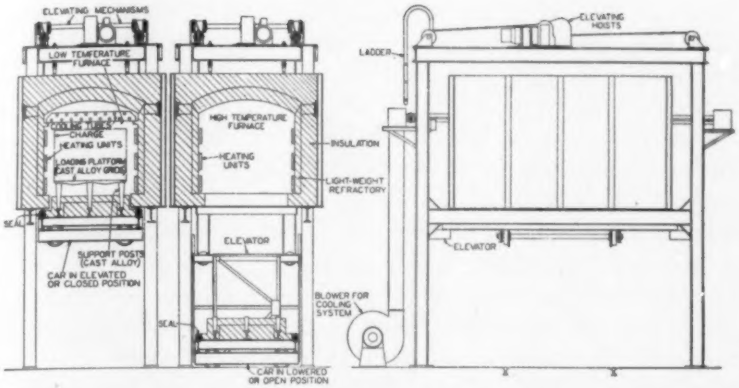

FIG. 7—TYPICAL LAYOUT OF TWO, ELEVATOR-TYPE, ELECTRIC MALLEABLE ANNEALING FURNACES.

varies from 36 to 42 hours, depending on the weight of charge. The average energy consumption is 400 k.w.h. per net ton.

34. An installation of two furnaces, located side by side, is illustrated in the Fig. 7. It will be noted from this drawing that each furnace has its own motor-driven elevating mechanism and the low-temperature furnace is equipped with its auxiliary cooling system. An installation of two-chamber furnace equipment is shown in the Fig. 8.

35. There are two of these installations at this one plant and each of the furnaces is suitable to take a car having loading platform of 51-in. wide by 102-in. long with a loading height of approximately 38-in. The car is loaded with a total of sixteen containers, giving a net charge of 8,000 lb. of castings, and a gross charge of slightly more than 10,000 lb., including containers.

36. In this particular installation, the analysis of the iron being annealed is as follows: Silicon, 1.30 to 1.35 percent; carbon, 2.30 to 2.35 percent; and manganese, 0.38 percent.

Annealing Cycle

37. The annealing cycle is approximately as follows: The charge, as described above, is placed in the furnace with the furnace at approximately full temperature and this cold charge is brought to a temperature of approximately 1700°F. in 7 hours and then the charge is held at that temperature for a period of 5 hours, making a total of 12 hours' time in the high-temperature furnace.

38. At the end of the 12-hour cycle, the hot charge is removed from the high-temperature furnace and immediately placed in the low-temperature chamber, where the temperature is automatically lowered to approximately 1400°F., requiring approximately 5 hours' total time to equalize the charge at 1400°F. The charge is then slow-cooled at the rate of approximately 20°F. per hour for the remaining portion of the time, or approximately 7 hours, giving a total of 12 hours in the low-temperature chamber.

39. This equalizing and cooling program is entirely automatic, as the equipment is provided with an adjustable program controller that throws the heat or the cooling system on and off as required to accurately control the time-temperature cycle.

40. The economy of operation on the above loading and production, based on an average of several hundred heats, is 300 k.w.h. per net ton of castings.

FURNACES FOR PEARLITIC IRONS

41. This type of equipment is also being used for the treatment of pearlitic iron. The cycle for the pearlitic iron in the high-temperature chamber is approximately the same as above, but the

FIG. 8—INSTALLATION SHOWING TWO, TWO-CHAMBER, ELEVATOR-TYPE, ELECTRIC MALLEABLE ANNEALING FURNACES. THE CAR LOADING PLATFORM IS 51-IN. WIDE, 102-IN. LONG, AND LOADING HEIGHT IS 38-IN.

charge is removed from the high-temperature chamber and is rapidly cooled outside of the furnace by means of suitable air blast. The castings are cooled to a temperature of 900 to 1000°F., and then placed in the low-temperature furnace for reheating to a higher temperature in the neighborhood of 1400°F.

42. Such a furnace, as described, has a normal rating for the high-temperature furnace of approximately 250 k.w., and the low-temperature furnace is rated from 100 to 150 k.w., depending on the cycle desired.

43. The data given in Table 2 are the estimated economies of a two-chamber, electric furnace installation, one furnace being used for the high-temperature portion of the cycle and the other for the low-temperature portion. The data also are based on furnaces with a car-loading platform 51-in. wide, 102-in. long, loading height 38-in., net charge 8,000 lb., loaded in 16 containers.

Table 2

ENERGY CONSUMPTION ON TWO-CHAMBER, ELECTRIC FURNACE INSTALLATION

Charge Number	*Annealing Cycle* Hours Held at 1750°F.	Hours Held at 1300-1400°F. or Slow-cooled	Total Cycle, Hours	Charges per 24-hr. Day	K.W.H. per Net Ton
1	5	6	24	2.00	300
2	10	10	34	1.41	350
3	15	15	44	1.09	410

44. For those foundries with smaller production, as well as for larger foundries desiring increased flexibility of annealing equipment, this type of furnace warrants serious consideration. By use of the two-chamber furnace, the economy of operation approaches that of continuous-type of furnace.

SOME ADVANTAGES OF ELECTRIC MALLEABLE ANNEALING FURNACES

45. By the use of the modern-type, electric furnace for annealing malleable iron castings, the heavy cast pots and packing materials are eliminated. This not only shortens the time for annealing and greatly reduces the weight of material to heat, but also decreases the cost of containers required, eliminates the cost of the packing material and greatly decreases the labor required for loading and unloading of the furnace and castings, as well as providing better working conditions.

46. The shorter annealing time makes possible shorter shipments and less inventory. The saving in floor space, due to the shorter annealing time will be 50 percent or more.

47. In an electric furnace, the heating units can be located where desired, and in the amount desired, thereby providing accurate temperature control and uniform temperature distribution. This distribution of heat in an electric furnace remains constant, therefore, making it possible to duplicate results with a minimum of attendance, and insuring uniform quality of annealing day in and day out.

(Discussion for entire Symposium will be found on pages 133-148, inclusive.)

Graphitization Symposium—VII

Graphitization of Arrested Anneal Malleable Iron

By D. P. Forbes*, Rockford, Ill.

Abstract

Two processes are used commercially for the production of arrested anneal malleable iron. The first method consists of completing the anneal with the retained combined carbon by a suitable time-temperature cycle. The second method follows a procedure of completely annealing the castings so that practically no combined carbon remains in the matrix and then reheating the castings to a predetermined temperature so that the temper carbon goes back into solution in the matrix. The author discusses both of these methods in detail, including the metallurgical changes occurring in the iron during the annealing by these two methods.

1. The principles for graphitization in normal malleable iron hold true for pearlitic malleable iron, bearing in mind that in the final product a certain percentage of the total carbon must be present in the combined form. This type of material has been called by several different names, all of which refer to the same class of materials. The more common names are "arrested anneal malleable", "pearlitic malleable", and "graphitic steel**". Because no one term has been entirely satisfactory and because the physical properties of the various materials are not identical, individual manufacturers have been inclined to use trade names for their particular products. Examples of such names are Promal, ArMa Steel, Z-Metal, to mention only a few.

2. Pearlitic malleable is defined[1] as "any material which starts out as white cast iron and is subsequently heat treated to produce

* President, Gunite Foundries Corp.
** Not to be confused with graphitizable steel which is an entirely different material.
1 *"Symposium on Pearlitic Malleable Cast Iron"* held at a meeting sponsored jointly by A. F. A. and the Cleveland District Committee, American Society for Testing Materials, Cleveland, Ohio, Jan. 27, 1936.
Note: This paper was presented at a Malleable Session of the 46th Annual A.F.A. Convention, O., April 21, 1942.

graphitization . . . if the graphitization be purposely terminated when sufficient combined carbon remains to significantly affect the properties of the product. The combined carbon usually is present as pearlite, although it frequently may be present as sorbite or might be martensitic or some other form of decomposition product of austenite."

3. While it is entirely proper to consider any partly graphitized white iron as pearlitic malleable, there has as yet been no important commercial use of iron of the type in which any of the original massive cementite present in the white iron is permitted to remain in the finished product. Therefore, in this paper, there will be no discussion of the methods of producing, or of the physical properties of, a material of this nature.

4. Considering, therefore, only the type of material in which the massive cementite has been eliminated in the first stage of annealing, the subject then becomes one of incomplete graphitization of the combined carbon present in austenite and pearlite, which makes up the matrix of the metal.

5. First stage annealing having gone to completion, and disregarding the carbon which may have been lost due to decarburization, we then have present in the metal, graphite in the form of temper carbon to an amount equal to the mathematical difference between the total carbon and the combined carbon retained in austenite or pearlite at the end of the first stage of annealing.

Commercial Processes

6. Commercial processes for obtaining a final metal with combined carbon in the matrix may be broadly divided into two methods: The first method consists in completing the anneal with retained combined carbon by a suitable time and temperature cycle, which constitutes "arrested anneal" in the strictest sense. The second method follows a procedure of completely annealing the castings so that practically no combined carbon remains in the matrix, which is then reheated to a point above the A_{gr} line so that temper carbon goes back into solution in the matrix. This combined carbon is retained in the matrix by quenching in a liquid or by cooling with a time-temperature cycle designed to retain the desired percentage of combined carbon and to result in the desired microstructure. This may be accomplished as a continuous cycle or may require subsequent heat treatment.

7. Commercial methods also vary with the analysis of the white iron under treatment. Under some circumstances, it is beneficial to add an alloy for the purpose of slowing up graphitization during second stage annealing. The use of such alloys forms a modification of the two general methods previously mentioned and this will be discussed later.

GRAPHITIZATION BY ARRESTED ANNEAL

8. Starting at the point in the anneal when decomposition of massive cementite has been completed, the metal consists of temper carbon nodules more or less uniformly distributed throughout a matrix of austenite. The austenite crystals may not be completely homogeneous and, for any given temperature, may vary in carbon content from the maximum saturation, as determined by the A_{cm} line of the metastable iron-carbon diagram, to the saturation shown by the A_{gr} line of the stable diagram. This is due to the fact that the austenite-cementite interface was controlled by metastable conditions, whereas the austenite-graphite interface was controlled by stable conditions. However, any commercial annealing cycle would probably allow a factor of safety of time at the first stage temperature to permit migration in the austenite to reach approximate stability.

9. If such a metal at a temperature of, say 1700°F., were rapidly lowered in temperature by quenching or air cooling, sufficient time would not elapse to allow the combined carbon content of the austenite crystals to reduce to the point of balance with the A_{gr} line of the stable diagram. In fact, the combined carbon content might even be in excess of that which can be retained in solution in austenite under metastable conditions. Under such a condition, cementite might be rejected to the grain boundaries as is the case with hyper-eutectoid steel. There is evidence that such cementite formation is formed by cooling from 1700°F. to the critical temperature in a moderate period of time, say at the rate of 500°F. per hour. To avoid such a rejection of cementite to the austenite grain boundaries, the metal should either be cooled slowly enough above the critical range so that the excess of combined carbon will migrate to and be converted into temper carbon, or else the metal should be so drastically quenched that the super-saturated austenite would be converted into martensite within a matter of a few seconds.

10. The danger of the formation of grain boundary cementite

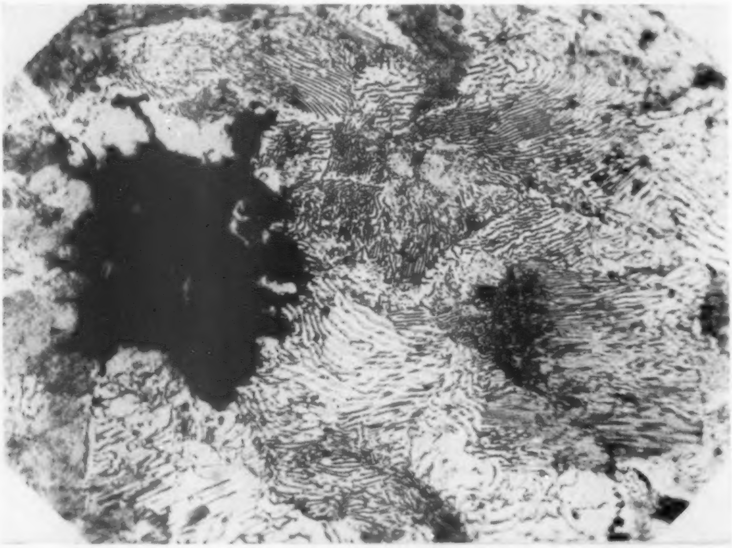

FIG. 1—EXAMPLE OF ARRESTED ANNEAL MALLEABLE WITH PEARLITIC MATRIX. TRACE OF FERRITE ADJACENT TO TEMPER CARBON NODULE. ETCHED. MAGNIFICATION, x500. (COURTESY, NATIONAL MALLEABLE & STEEL CASTINGS CO.)

is not serious in most commercial operations if the furnace charge is reduced in temperature at a rate which will not permit such a formation; for example, from 1700°F. the furnace charge could be reduced to 1450°F. in a period of approximately 2 hours, which experience has indicated will prevent the grain boundary formation.

11. The temperature interval between the stable and metastable critical temperatures brings into play reaction rates of a highly complicated nature. For practical purposes, however, in considering pearlitic malleable, this interval may be disregarded because every effort is made to pass through the critical range rather quickly, instead of slowly, as would be the case if completely graphitized malleable were desired. Therefore, for the purposes of this paper, this interval is disregarded.

Control of Combined Carbon

12. If the metal passes through the critical temperature range with moderate rapidity, the combined carbon content of the matrix is determined by the A_{sr} line of the stable diagram and the temperature from which the metal was quenched or rapidly cooled.

13. This percentage of combined carbon in the matrix is not stable at temperatures just below the critical range and will tend to graphitize in accordance with the principles of graphitization applying to normal malleable iron. If, therefore, a large percentage of combined carbon in the matrix is desired, the metal should not be permitted to remain at sub-critical graphitizing temperatures for any substantial period of time.

14. Conversely, if a low percentage of combined carbon is desired, sub-critical graphitization should be permitted to proceed by the desired amount. This graphitization proceeds quite rapidly just below the critical range. As a consequence, time is saved if the temperature of this stage of the heat treatment is not permitted to be held too far below the critical range.

Effect of Cooling Rate Through Critical Temperature on Structure

15. Austenite, in castings of this type, apparently decomposes into its decomposition products in much the same manner as austenite of the same analysis in steel. The presence of temper carbon in the pearlitic malleable seems to produce only the effect of decarburizing the metallic grains adjacent to it.

16. The austenite of the pearlitic malleable, therefore, if passing through the critical range drastically, as by means of a liquid quench, will result in a martensitic matrix, and if rapidly cooled, as by cooling in air at the rate of say 400°F. per hour, will form fine pearlite or sorbite. Slower cooling will result in coarse pearlite, with the presence of some ferrite, because of decarburization adjacent to the temper carbon grains (See Fig. 1).

17. Conceivably, particularly in the presence of alloys, the austenite could be reduced to room temperature without decomposition, resulting in an austenitic iron which would still probably fall into the pearlitic malleable classification. Materials of this type have been produced in which the matrix was preponderantly austenitic; the metal was practically non-magnetic, was very soft in the as-quenched condition, and at the same time almost unmachineable because of its tendency toward work-hardening. The properties apparently were similar to those of austenitic manganese steel.

18. It is seen, therefore, that below the critical temperature a matrix may be formed with a combined carbon content ranging

from the eutectoid composition (or even higher) down to a matrix practically carbon-free. Furthermore, the combined carbon can be in the form of austenite or any of its decomposition products. These decomposition products can be further heat treated to develop special properties or structure, just as steels can be heat treated. For example, a martensitic matrix (See Fig. 2) can be tempered to any degree of hardness, or a pearlitic matrix can be spheroidized (See Fig. 3). It must be borne in mind, however, that the presence of temper carbon nodules exerts a powerful decarburizing influence on the matrix. This is so marked that in spheroidizing a pearlitic matrix the combined carbon may largely disappear before the spheroids have an opportunity to form completely.

19. Recent work on the "austenizing" of partly-graphitized white iron at constant sub-critical temperatures indicates that the metal behaves in the same manner as steel containing no graphite. The metal, presumably because of its high silicon content, reacts slowly and therefore can be classed as a deep hardening material. Substantial shortening of the annealing cycle is a possibility as a result of this work.

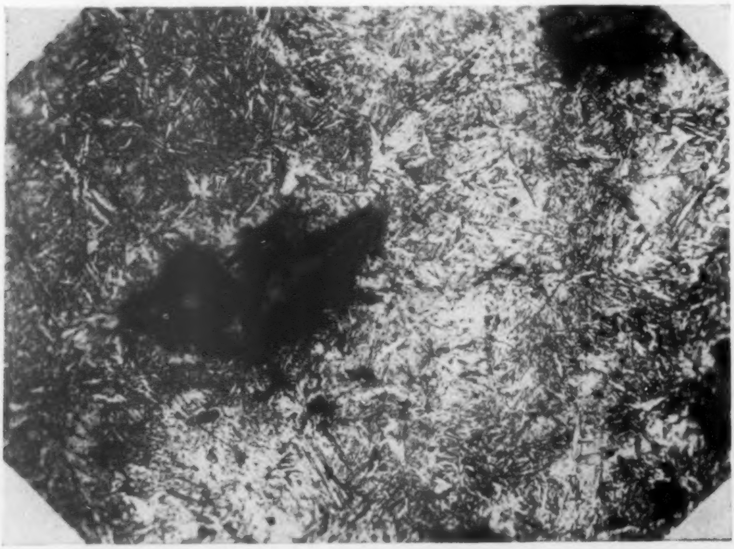

FIG. 2—EXAMPLE OF ARRESTED ANNEAL MALLEABLE IRON WITH MARTENSITIC MATRIX. DARK CONSTITUENT IS TEMPER CARBON. ETCHED. MAGNIFICATION, x400. (COURTESY, NATIONAL MALLEABLE & STEEL CASTINGS CO.)

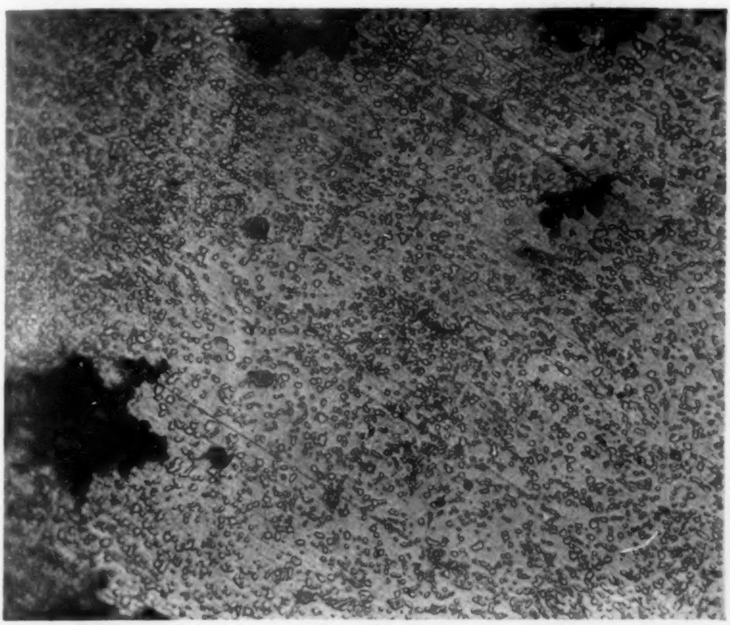

FIG. 3—EXAMPLE OF ARRESTED ANNEAL MALLEABLE IRON IN WHICH THE COMBINED CARBON IN THE MATRIX HAS BEEN SPHEROIDIZED. MANGANESE IS PRESENT TO RETARD GRAPHITIZATION. ETCHED. MAGNIFICATION, x500.

Graphitization by Second Method

20. The process of retaining combined carbon in the matrix by the first method, as just described, involves a close control of the time and temperature relationship toward the end of the annealing cycle. The alternate method follows the procedure of first producing completely graphitized iron. The iron is subsequently reheated (usually in a separate furnace) to a temperature above the critical range. The ferrite of the matrix probably does not change to gamma iron when the metastable critical temperature is passed, but when the stable critical temperature is reached temper carbon begins to redissolve, which permits the formation of austenite.

21. The mechanism of recarburization of austenite on reheating differs from the decarburization of austenite when cooling. Photomicrographs of malleable iron heated above the stable critical temperature show combined carbon at the grain boundaries of what was formerly ferrite and it seems that this combined carbon migrates along the grain boundaries rapidly because it promptly

forms a network pattern throughout the matrix (See Fig. 4). The photomicrographs, being made from quenched specimens, show the combined carbon in the form of martensite which indicates that the grain boundaries and the margins of the grains were austenitic. As time passes, the carbon diffuses into the grains from the grain boundaries until the entire matrix contains combined carbon up to the saturation point indicated by the A_{gr} line of the stable diagram. The higher the temperature to which the metal is heated, the faster does the combined carbon diffuse into the grains and the higher is the percentage which will saturate the metal. This recombination of carbon from temper carbon is extremely rapid, particularly at high temperatures, and is utilized in flame and induction hardening of malleable parts, where the heating cycle is limited to a few seconds only.

22. Providing the metal, in the second method, is heated to a uniform temperature and held for a sufficient period of time to produce equilibrium, it will be substantially the same as the metal produced by the first method of treatment, which has been cooled to the same temperature and allowed to attain equilibrium. Conse-

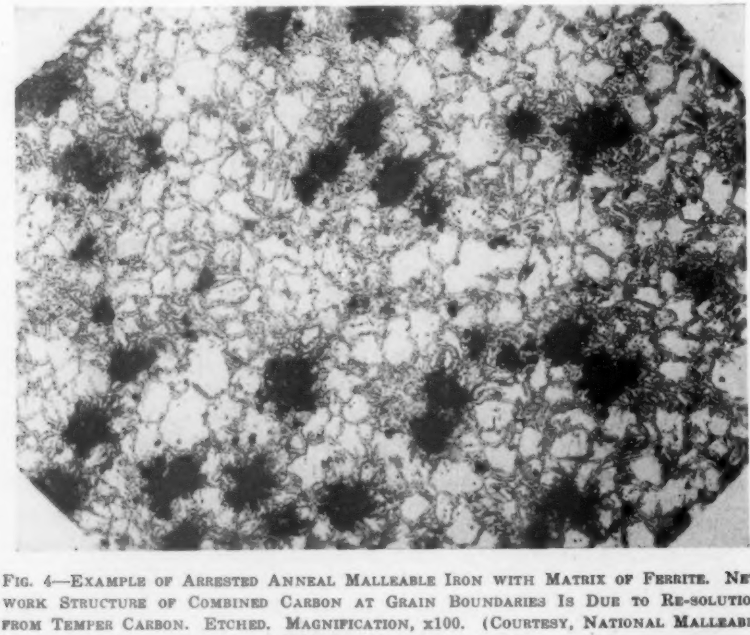

FIG. 4—EXAMPLE OF ARRESTED ANNEAL MALLEABLE IRON WITH MATRIX OF FERRITE. NETWORK STRUCTURE OF COMBINED CARBON AT GRAIN BOUNDARIES IS DUE TO RE-SOLUTION FROM TEMPER CARBON. ETCHED. MAGNIFICATION, x100. (COURTESY, NATIONAL MALLEABLE & STEEL CASTINGS CO.)

quently, the quenching, air cooling, or slow cooling discussed in the first method applies with equal force to the second method after equilibrium is attained. It should be pointed out, however, that where equilibrium at a temperature just above the critical is necessary in the first method to avoid grain boundary cementite and lack of uniformity of the matrix, by the same token, failure to attain equilibrium above the critical in the second method will result in the formation of grains which are high in combined carbon at the boundaries and low in combined carbon at the center. This condition of non-uniformity may be detrimental or beneficial, depending upon the characteristics of matrix desired.

Use of Alloys Affecting Graphitization

23. The foregoing discussion of the two principal methods by which pearlitic malleable is produced, applies in general to all analyses of white iron which are capable of graphitization. Alloying elements affect graphitization in different ways. All alloys have an influence on the position of the lines of the stable and metastable iron-carbon diagrams and will, therefore, influence the temperatures of the stable and metastable critical temperatures and also the percentage of combined carbon which can be retained in austenite, as shown by the A_{cr} line of the stable diagram.

24. But in addition to affecting the position of the lines in these diagrams, alloys may also have a profound influence on the rates of solution, migration, and precipitation of the carbon from chemical combination in cementite to solid solution in austenite to precipitation in temper carbon. Some elements, of which chromium is a typical example, act powerfully to restrain decomposition of massive cementite and formation of graphite during first stage annealing.

25. Other alloys, of which manganese is typical (and, when manganese is referred to, the amount of manganese in combination with sulphur probably should be disregarded) have relatively little effect on the rate of decomposition of massive cementite but do have an important effect on the elimination of combined carbon from austenite and its decomposition products during second stage annealing.

26. Still other alloys, of which silicon is a typical example, act to *accelerate* graphitizing rates in both stages of annealing. A *re-*

duction of silicon, therefore, promotes the retention of combined carbon in the final product.

27. In considering the effect of alloys on graphitization, it must be remembered that the effect is only apparent if the heat treating cycle is not altered, or to put the statement another way, completely graphitized malleable iron can be produced in the presence of alloys, providing the heat treating cycle is prolonged or altered in some other way to allow for the effect of the alloy on graphitizing behavior.

Objects in Use of Alloys

28. In commercial practice, the alloys used in production of pearlitic malleable serve one or more of three objects. One object is to permit metal of normal malleable analysis and alloyed metal to be heat treated side by side, using a normal malleableizing cycle which would produce normal malleable iron from the unalloyed material and pearlitic malleable from the alloyed material. In commercial operations where only a limited amount of production is in the form of pearlitic malleable, this procedure has obvious advantages.

29. Another reason for using alloys is to prevent complete graphitization of combined carbon where a heat treatment is necessary to develop a specific structure which requires exposure for a considerable period of time to temperatures where graphitization can also proceed. A matrix of spheroidized pearlite results in a considerable increase in ductility in pearlitic malleable. Alloys (usually manganese) prevent graphitization from going to completion at the temperatures best suited for spheroidization.

30. Alloys to retard graphitization serve a third important purpose, namely, to promote uniformity of product. The graphitization of white iron is influenced by many factors which may vary from heat to heat, or even between castings of one metal thickness and those of another, produced in the same heat. By introducing a graphitization retardant, the influence of the other graphitization factors becomes relatively less important and, although a little additional time may be required to accomplish a certain result, the gain in uniformity of product is the more important consideration.

GENERAL COMMENTS

31. Pearlitic malleable iron, if properly produced, is a metal

combining factors of high strength and resistance to wear, for which some sacrifice has been made in machineability and ductility, as compared to normal malleable iron. It must be borne in mind that, to be of commercial value, the material must be uniform in properties from day to day and month to month. Haphazard production of this material by those not qualified technically, or not having proper equipment, is worse than no production at all. Such material is little better than the "under-annealed malleable" which has plagued malleable foundries every time something went wrong with the metal or the anneal.

Commercial Importance

32. The potential markets for pearlitic malleable have still not been completely explored, although new applications are being found almost daily. Pearlitic malleable will probably compete for business with normal malleable iron, steel castings, forgings, and. to a limited extent, stampings and non-ferrous metals.

33. When engineers are acquainted with the high physical properties of pearlitic malleables, they can quickly determine the extent to which this type of material can produce a better or less expensive part; and pearlitic malleable will find its sphere in the family of metals.

Physical Properties

34. The physical properties of this type of material are dependent primarily on the amount of combined carbon in the final product, and the form in which the combined carbon exists in the matrix. This, of course, is also true of steels of various carbon contents. Such a relationship is to be expected because pearlitic malleable consists of a steel matrix in which are embedded nodules of temper carbon. The elements, other than carbon, are less important in affecting physical properties than they are as a means of obtaining the desired final combined carbon structure. Here again the analogy to steel is close.

35. Pearlitic malleable being still in its infancy, standardization has not proceeded far enough to establish any standard specifications. Each producer makes the type of metal for which his equipment is best suited and which serves the needs of his market best.

36. There is enough similarity, however, between the grades of metal produced by different foundries to justify designation of

Table 1

PROPERTIES OF COMMERCIAL PEARLITIC MALLEABLE

Material	*Tensile Strength, lb. per sq. in.*	*Yield Point, lb. per sq. in.*	*Elongation in 2-in., percent*	*Brinell Hardness Number*
Z–Metal	70– 90,000	48–60,000	18.0– 8.0	155–255
Gunite K	97,000	75,000	4.0	227
Mallix	78,000		6.0	
ArMa Steel	80–108,000	50–95,000	5.0– 1.5	187–285
Promal	70– 75,000	50–55,000	14.0–10.0	170–190
Belmalloy	70– 80,000	45–50,000	10.0– 5.0	179–207
Perduro	91,000	72,500	6.0	187–217
Meehanite	45–120,000	30–80,000	15.0– 1.0	140–350
Cu–high Mn	60– 80,000	45–60,000	9.0– 5.0	210
Ni–Cr Alloy	62– 85,000	42–70,000	24.0– 5.0	130–250
High Silicon	55–115,000	41–80,000	15.0– 4.0	150–260

two or three standard types of material at the present time and it would be beneficial if action were taken in this direction in the near future.

General Properties

37. The most complete tabulation of physical properties published to date is to be found in C. H. Lorig's paper, "Properties of Commercial Pearlitic Malleable Iron." Table 1 is condensed from this paper.

HEAT TREATING EQUIPMENT

38. The heat treatment to which the iron is subjected during processing can be performed in a number of different types of heat treating furnaces. Choice of the type of furnace must take into consideration the daily tonnage to be heat treated, the type of heat treatment, and the funds available for investment. Furnace equipment can be divided into two principal types: viz., batch type and continuous type.

39. In the batch-type furnace, an entire charge is carried through the heat treating cycle as a unit. In the continuous-type furnace, castings enter the furnace at intervals, being conveyed from one temperature zone to another, in accordance with the time-temperature cycle desired.

40. In the batch-type process, two or more separate heating chambers may be employed, to avoid the necessity of alternately raising and lowering the temperature of a single compartment.

For example, a charge of castings may be placed in one chamber, heated to the first stage graphitizing temperature and held until the first stage of annealing is completed. Instead of permitting the temperature of the furnace to drop, which because of insulation would probably require considerable time, the charge may be withdrawn from the furnace and allowed to cool below the critical temperature in air. The charge can then be placed in a second chamber already preheated to the temperature of second stage annealing, which would permit the insertion of a fresh charge of castings in the high temperature compartment. In certain cases, three chambers might be used to advantage, the first chamber serving to raise the temperature up to the graphitizing temperature, the second chamber being used for first stage annealing, and the third chamber being used for second stage annealing.

41. The continuous type of furnace usually is provided with a conveyor which moves the castings progressively through various heating and cooling zones. Such a furnace for large production would be of considerable length. It is usual to have the hearth wide and to spread or pack the castings into a relatively thin layer. The height of the highest point of the charge above the level of the moving hearth rarely exceeds 18-in. Such furnaces are usually designed for a specific time and temperature cycle, with the heating elements arranged in such a way that adequate heat input is available to provide accurate temperature control. The burners or heating elements in each zone are controlled by individual pyrometers so that every casting passing through the furnace is subjected to the same time and temperature cycle, irrespective of varying load density.

42. Castings are customarily placed in open containers or trays without packing material of any kind. To avoid scale and decarburization, it is therefore necessary to prevent contact of the products of combustion with the castings. Furnaces for producing this type of material are almost exclusively heated either by radiant tubes or by electrical heating elements. Both types of equipment are widely used and economic conditions dictate the choice of one or the other.

43. Most furnaces have provisions for controlling the atmosphere surrounding the castings. The continuous type of furnace consequently requires gas tight vestibules to prevent loss of atmosphere.

44. Using the batch operation in a gas-tight furnace, the requirement for a protective atmosphere can sometimes be avoided. There is a considerable quantity of protective atmosphere automatically generated by the reaction between the carbon in the white iron castings and the initial air in the furnace. This atmosphere is usually sufficient to prevent all but superficial decarburization and scaling.

45. Where the time-temperature cycle calls for a rapid cool between the first and second annealing temperatures, continuous type furnaces can be provided with cooling coils handling air or water. The same type of cooling zone may also be provided at the end of the heat treating cycle to reduce the temperature of the castings so that they can be handled at the discharge end of the furnace*.

46. Certain time-temperature cycles may require a liquid quench, usually in oil, following a treatment in the graphitizing range. The quenching tank may be located at the discharge end of a continuous furnace or an entire charge may be quenched from a batch-type furnace. Where a liquid quench is used, a subsequent heat treatment is usually necessary and this heat treatment can be performed in either a continuous or batch-type furnace.

47. The choice between a batch-type or a continuous-type installation depends principally upon the requirements of the manufacturer. If his production is relatively steady, without variation in analysis, the continuous-type process has advantages. On the other hand, where operations may be intermittent or where the furnace equipment must handle different analyses or variations in the time-temperature cycle, the batch-type furnace will be found somewhat more flexible.

48. It must be emphasized that material of this type must be heat treated in furnaces capable of accurate temperature control. The uniformity of product can only be obtained by properly designed and controlled equipment.

(Discussion for entire Symposium will be found on pages 133-148, inclusive.)

* See also "*Electric Furnace Annealing*," by R. M. Cherry, Page 67.

Graphitization Symposium—VIII

Atmospheres and the Annealing of Malleable Iron

By R. J. Cowan*, Toledo, Ohio

Abstract

In this paper, the author elaborates on a paper previously presented before the Association. He outlines the reasons behind atmosphere control in malleable annealing furnaces and explains how the atmosphere must be balanced in order to influence the final product favorably. He discusses in detail the causes of pearlitic edges in malleable castings and the effect of packing materials. Of considerable interest is his discussion of causes of decarburization during both the first and second stages of the annealing cycle. As machinability is one of the main properties of malleable iron, the influence of structure on that property by the atmosphere surrounding the malleable iron during the annealing cycle is discussed. The latter part of the paper is devoted to a description of the type furnace in which controlled atmospheres are used, along with diagrammatic sketches of units for preparing various types of controlled atmospheres.

1. In a previous paper before the American Foundrymen's Association, the writer, along with E. G. deCoriolis, presented a discussion of the fundamental principles underlying the use of special atmospheres for annealing American malleable cast iron. The present paper is an elaboration of the preceding one with a view to clarifying certain aspects of the matter.

2. There are no unusual features of atmosphere control which apply to the malleable field alone, but only such as are being used daily in hundreds of installations for the heat treatment of ferrous metals. The principles thus applied, are used for the prevention of scale formation, to guard against decarburization during heat treatment, and for protecting metal surfaces from injurious attack

* Surface Combustion Corp.

Note: This paper was presented at a Malleable Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

by the surrounding atmospheres in the heat treating processes. Each of these matters is of interest and has a bearing on the subject being considered. The malleable anneal, however, calls for a combining of various steps in the matter of atmosphere control which are not found in other procedures.

3. It must be understood in the beginning that references in this paper to the malleable anneal have in mind the process of graphitization by heat treatment whereby the combined carbon of hard iron is converted into iron and temper graphite in the distinctive forms found in the malleable iron of commerce. This expression, "the anneal," so used, has a meaning much different from that intended when other "annealing" processes are referred to in ordinary metallurgy that do not involve a chemical change within the metal. This use is well established in the trade and generally well understood, but it is best to guard against any misunderstanding.

Various Structures in Malleableizing Process

4. The manufacture of malleable cast iron covers a very broad field of ferrous metallurgy. As a rule, the carbon content of iron serves as a convenient indicator of the heat treatment necessary to produce the results desired. Thus, the steels are classified as low, medium or high carbon on the basis of their "combined carbon" contents. Each of the products named are to be found, at some stage of malleable manufacture, constituting the basic matrix of the partially annealed iron. Furthermore, the cast iron structures come into consideration in the matter of graphitic carbon forms, both in the hard and the annealed irons.

5. The manufacturer of malleable iron must guard against primary graphite in the original hard iron to prevent its formation during annealing, thereby producing, instead of the desired product, a hybrid form of cast iron rather than of malleable. He also must conduct the annealing operation by using a type of temperature cycle that will insure the absence of combined carbon in the matrix of the metal. It is evident that the manufacture of a commercial metal which covers so wide a range of structures, intermediate between the high carbon of the original hard iron and the final ferritic form of the annealed iron, must present problems also in the matter of atmospheres that surround this metal in the various stages of heat treatment.

6. Obviously, a high carbon iron will require an atmosphere

for its protection that is very different from that required by a low carbon iron. The problems that arise in connection with this matter have to do with the combinations of gases that are brought together at different stages to attain the varying objectives encountered during the anneal.

Atmospheres Required in Annealing Cycle

7. A casual consideration of the matter will indicate, that at times during the anneal, there will be required an atmosphere that is highly carburizing in its effects on the metal, and at other stages, there will be times when such an atmosphere must be sedulously avoided. An atmosphere at equilibrium with a high carbon steel. such as that found in the metal matrix at certain stages of the anneal, will not be in equilibrium with the matrix of ferrite (carbon-free iron) in the final product. Since the metal changes during annealing from a very high carbon one to one that is free from carbon (in the combined form), it would seem that these changes in metal composition should be followed by a corresponding change in the atmosphere to maintain a condition of chemical equilibrium at all times and thereby prevent reaction with the metal and obtain the full benefit of atmosphere control.

8. Attempts have been made to meet this condition by producing an atmosphere of constantly changing composition which would, at all times, be in chemical equilibrium with the metal in the successive stages of heat treatment. While it is possible to do this, it has not been fcund to be necessary. Furthermore, it requires a vigilance of operating control not usually considered to be within commercial brackets. Fortunately, there are certain broad requirements which, when observed, will insure a superior product; and these are well within the usual commercial operating ranges. The atmospheres referred to are easily prepared and readily applied and, when used intelligently, produce results that in certain respects are superior to those obtainable by the more elaborate methods.

Causes of "Pearlitic Edges"

9. Before taking up the consideration of these special atmospheres in a more detailed form, it may be well, at this point, to give some attention to the matter of "pearlitic edges" which have been such a prolific source of trouble to the industry, and which continue to persist all too frequently in the usual type commercial

practice, in spite of the time and attention that have been given to the matter. The reference here is to the hard edge which forms as a "picture frame" or "shell" of white metal around a core structure that is fully black in appearance. It is believed that this structure is due very largely to the atmosphere which surrounds the metal during annealing. It must be remembered, even though the metal be surrounded by a packing material, it is still, in reality, encompassed by an atmosphere; and that this atmosphere affects the rate of annealing in a most important manner.

10. To confirm this, it is only necessary to recall the care that is taken to insure the right condition of the packing material in every case where a shortened annealing time is being sought. An active packing gives results that are different from those obtained by using an inactive one. Many "pearlitic edges" are caused by an improper packing material coupled with an incorrect temperature cycle. This suggests a relationship between annealability and packing material, or more correctly, between the rate of annealing and the atmosphere that surrounds the metal during its heat treatment.

Effect of Packing Materials

11. When it is said that, "An active packing, with a given annealing cycle, will produce a greater depth of white edge than an inactive one" it serves to call our attention to a very important fact, and at once we are concerned with finding out why this should be so. Analyses of the packing materials indicate that the active ones contain ferric oxide, and that this increases in amount with the degree of activity. This recalls to memory the methods formerly used for oxidizing artificially the materials used for packing—sal ammoniac, etc.

12. When ferric oxide is heated in contact with high carbon iron, the oxygen which it contains in combination, reacts with the carbon of the iron to form carbon monoxide which is a combustible gas. Every one is familiar with the burning that occurs when gases from the annealing pots come into contact with the furnace atmosphere but few stop to reflect that these gases are coming in reality from the carbon of the metal by reaction with ferric oxide of the packing with iron carbide of the castings. This fact alone, which is so well known to all, serves as conclusive proof that decarburization of the metal is a common occurrence in the usual annealing procedures.

Causes of Decarburization During First Stage of Annealing Cycle

13. At this point, it would seem to be the logical thing to inquire as to the kind of effect decarburization has upon the metal being annealed. In direct reply to this query, it can be stated with confidence, that in the first stages of annealing, decarburization can serve no useful or beneficial purpose. On the contrary, it seems that the extent of this decarburization which occurs in "first stage" or high temperature annealing will prolong the "second stage" or cooling range portion of the cycle. A brief consideration will show why this must be so.

14. It is well known that a high carbon iron will anneal much more rapidly in "first stage" than a low carbon iron. That is to say, an iron containing 2.70 per cent carbon will anneal completely (first stage) in a very short time, but, if the iron contains only 1.70 per cent carbon, it will require a hold of many hours to complete this stage of the anneal. If the heart of the casting contains 2.70 per cent carbon while the edge of the same casting contains only 1.70 per cent carbon, which is the result of decarburization during the early stages of heat treatment, it is apparent that the edge metal cannot anneal at the same rate as the core metal, and that this condition will extend inwardly toward the core until a point is reached where the carbon content corresponds with the annealability limit of the temperature. If the metal be held at temperature for a time that is long enough to anneal the lowest carbon that is produced by the amount of decarburization that has occurred, then the time required for "second stage" annealing will not be affected adversely.

15. As a rule this is not the case and the usual annealing cycles will not take care of a strongly decarburized iron. The degree of decarburization in these cases exceeds the time limit of the usual annealing cycles and consequently there is carried over into the "second stage" an un-graphitized edge that will require a very long time in this stage to anneal completely. Since the usual "second stage" cycle is not sufficiently long to take care of this, there will be a "pearlitic edge" on the casting with all the attendant annoyances.

16. These considerations prove abundantly that decarburization during the first part of the annealing cycle is a thing to be avoided as much as possible, since it always serves to extend the over-all annealing time, and always in direct relation to its extent. This is a clue to the reason why a radical change of packing

material will always affect the annealing cycle unless this cycle be unduly prolonged. In practice, it is customary to develop a safe time limit that will take care of the ordinary variables that occur in annealing. In any effort to reduce the time required for annealing without any change of metal composition, it is necessary to watch very carefully, the matter of decarburization, since this always results in an extension of the annealing time required for first stage or second stage or both; and in either case will be considerable.

Decarburization During Second Stage of Annealing Cycle

17. Thus far in the discussion, the matter of decarburization has been considered in connection with the early portions of the annealing cycle. At such times, the effect is always objectionable. The conditions that exist in "second stage" annealing, however, are not such as preclude the use of such a gas at this time. In fact, the indications are that a gas of this kind may be used to advantage during this portion of the anneal. There is before us then the interesting observation that in one part of the annealing cycle a decarburizing gas atmosphere may not be used while in another and succeeding portion of the same cycle it may be desirable. This matter will certainly warrant further consideration.

18. At the completion of "first stage" annealing, the metal has a matrix that still retains a lot of carbon—being in this respect equivalent to a high carbon steel. Within this structure, graphitiza-

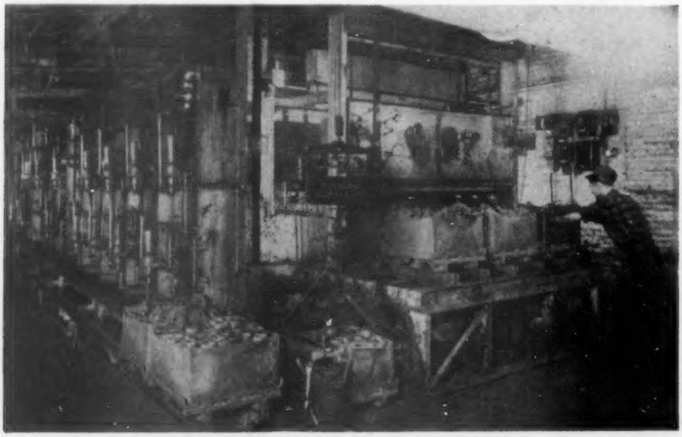

FIG. 1—MALLEABLE ANNEALING FURNACE EQUIPPED WITH ATMOSPHERE CONTROL.

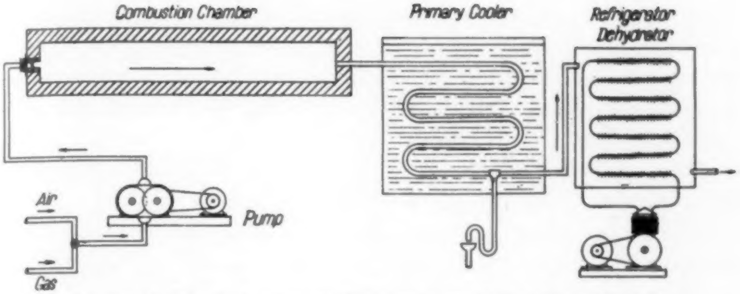

FIG. 2—SCHEMATIC LAYOUT OF EQUIPMENT FOR GENERATING DX GAS.

tion is progressing, although the rate is decreasing as the temperature is lowered, as it is in this stage of annealing. It is seldom the case in commercial practice that the iron at this point is uniform in carbon content throughout the entire structure from core to surface of the casting. It usually is found that the carbon is lower in the portions that are at or near the edges. This may be dealt with in one of two ways.

19. In each case the carbon will be removed from combination in the matrix, but in one case this removal will be by graphitization and in the other by oxidization. It is quite conceivable that carbon may be removed from the edge portions of the structure in a more rapid manner by being oxidized from the surface than by being graphitized by prolonged annealing, such as is required by low carbon areas of this kind, as has been shown. Cases are observed from time to time in commercial practice, where a decarburized edge on the annealed casting, consisting wholly of ferrite, overlays a pearlitic structure which disappears in the completely annealed core. The explanation of this seems to be that there has been, during "first stage," a strongly decarburizing action which has produced what, by ordinary annealing, would have been a deep pearlitic rim, but this rim has been removed by subsequent oxidization during "second stage" so that the remaining pearlite is deep-seated and probably objectionable from the standpoint of machinability for this very reason.

20. These facts seem to suggest that it might be possible, by a certain amount of juggling, to find an atmosphere that would not be too strongly decarburizing during first stage and at the same time sufficiently decarburizing during second stage to remove from the metal surface the objectionable effects of the incomplete first

stage. These facts are probably the underlying fundamentals which determine many of the empirical methods that are used for annealing and which have been arrived at by local plant experimentation. It will be in order now to inquire as to whether this might not constitute good practice.

Structure vs. Machinability in Malleable Iron

21. In considering this matter, account must be taken of the problem of machinability, which is always a prime object in malleable iron manufacture. Experience has shown that a deep ferritic edge on castings tends to clog the cutting tool by building up on its edges and thereby causing the tool to burn and the metal to tear. A pearlitic edge is hard and tends to slow the machining rate. Each of these conditions should be avoided to produce an iron of maximum quality.

22. On the other hand, if the edge portion of a malleable casting could be made to machine as easily as the core portion, there would result an important improvement of the product that would be very desirable. Such a condition, where the temper carbon of the same form as that found in the core of the casting extends to the very edge structure thereby providing a natural graphitic lubricant, serves to facilitate machining of the ferritic matrix. A product of this kind will certainly represent malleable iron at its best, and is a product well within the bounds of commercial feasibility.

23. To produce a metal of these characteristics, it is necessary to avoid all traces of decarburization during "first stage" anneal-

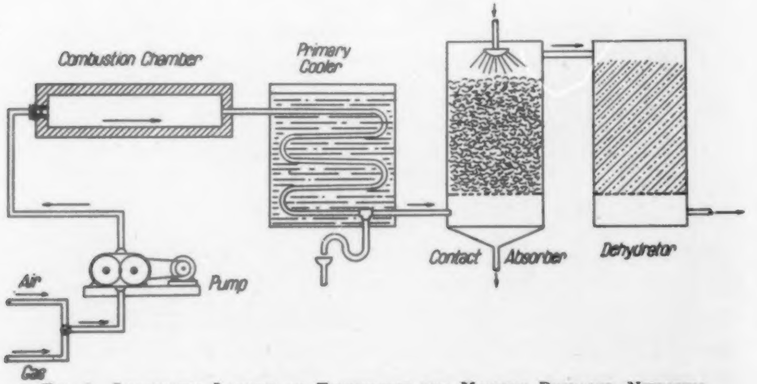

FIG. 3—SCHEMATIC LAYOUT OF EQUIPMENT FOR MAKING PREPARED NITROGEN.

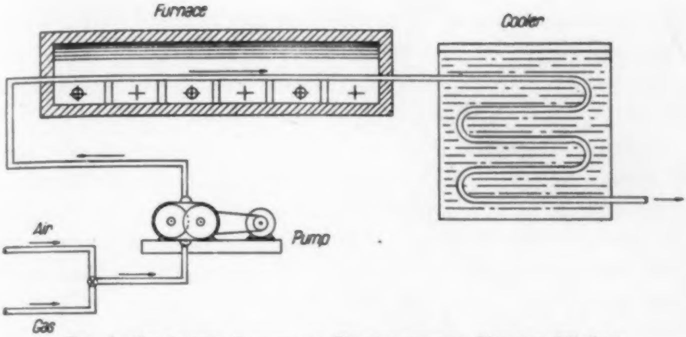

FIG. 4—SCHEMATIC LAYOUT OF EQUIPMENT FOR MAKING CG GAS.

ing. It is impossible to do this by the use of any kind of packing material. Even materials free from iron oxides will entrap sufficient air to remove carbon from the surface of the castings. The only way known to the writer in which this can be done is by the use of an atmosphere especially prepared for the purpose.

24. This will consist of a gas, or mixture of gases, usually referred to as "carburizing." This term is commonly used in the sense that is well known in the heat treatment of steel. In this sense, any gas, or mixture of gases, that has the power of adding carbon to a low carbon steel is "carburizing." As a rule, such a carburizing process will add to the steel an amount of carbon that will bring the total to a value of about 1.20 per cent. This is well below the carbon content of the usual hard iron from which malleable is made.

25. To prevent decarburization of hard iron, an atmosphere must be used that is strongly carburizing in the steel sense. Undiluted natural gas or other hydrocarbon gas is such an atmosphere. Such gas has a strong tendency to carburize any of the ferrous materials and is well adapted for this kind of use. It must be used, however, with an understanding of its characteristics to obtain the desired results and avoid the limitations inherent in its use.

Changes Occurring During First Stage Graphitization

26. Considering, as we are, the characteristics of the atmosphere surrounding the iron during the first stages of annealing, it is necessary to visualize as clearly as possible, the changes that are occurring progressively in the metal during the prolonged period

at this high temperature. After the iron has reached full temperature, graphitization of the combined carbon proceeds rapidly so that, in a comparatively short time, the carbon of the matrix is very much reduced in amount.

27. When this reaction goes on in the presence of an atmosphere that is rich in hydrocarbons, there will come a time when it will cease to be protective only, in the sense of preventing the loss of carbon from the metal, and will indeed begin to carburize the iron and particularly so when the carbon content of the matrix becomes so low as to allow such a reaction to go on. If such an atmosphere be maintained throughout the entire "first stage" annealing period, the surfaces of the castings will be found to have a sheath of carburized metal surrounding them of a form that is almost impossible to graphitize. This fact must be understood and recognized as an important limitation in the use of hydrocarbons or similar gases as protective atmospheres. From a practical viewpoint, however, the matter is controlled very easily. Experience has shown that if the flow of these gases be discontinued at a time when the metal has been at the maximum temperature for a period of about 2 hours, there will be no injurious effects from this reaction and this time will be sufficient to insure complete protection against decarburization. This will retain the original car-

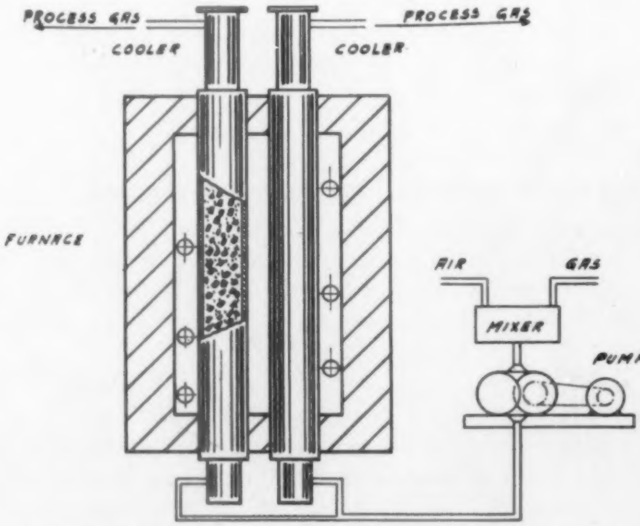

FIG. 5—SCHEMATIC LAYOUT OF EQUIPMENT FOR MAKING XO GAS.

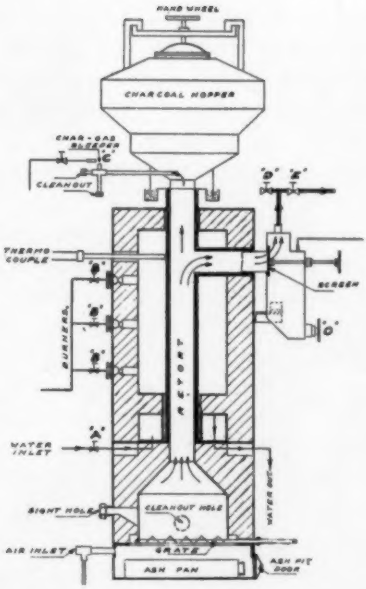

FIG. 6—SCHEMATIC LAYOUT OF EQUIPMENT FOR MAKING CHAR-MO GAS.

bon content in the surface of the metal.

28. When this is done, the time required for "first stage" is much reduced below the usual periods and there will result a metal that will respond much more readily to "second stage" annealing and the result will be an annealing time that is much below the usual standards for the manufacture of malleable iron of the usual chemical specifications. The writer knows of no plant where these principles are being used to the fullest degree. A full utilization will improve the product, reduce annealing time, and overcome a number of the handicaps to which the material has been subject for a long time.

29. The discussion of this subject has been carried on along the lines of well-known observations of a practical nature. It is hoped that bringing them together in this fashion may serve a useful purpose and aid in advancing the progress of this most interesting art.

Gas Generation Equipment

30. Fig. 1 shows a view of an industrial furnace that is used for annealing malleable iron in a special atmosphere. This is continuous

in type and heated by radiant tube elements that are gas-fired and extend across the furnace from side to side. They are fixed from both sides of the furnace. Vestibules at each end protect the atmosphere during charging and discharging of the chamber. A special type carriage carries the load of castings and is arranged for suitable lubrication. Furnaces of this type are being operated in various places in accordance with local plant requirements.

31. For the preparation of suitable atmospheres, a variety of generators may be used that provide uniform gases of particular character. These gases may be used alone or in combination with the usual commercial gases to produce the results desired. For convenience, a number of diagrammatic sketches are shown which portray the underlying principles of construction used for various types of gases. Fig. 2 shows the unit for the preparation of the so-called "DX" gas; Fig. 3, for prepared nitrogen; Fig. 4, for "CG" gas; Fig. 5, for "XO" gas; and Fig. 6, for "char-mo" gas. Table 1 gives the approximate composition of each of these gases.

32. These gases have been found suitable for a wide variety of metallurgical operations. In compact form, they provide gases of constant composition that may be utilized by the manufacturer of malleable iron to good advantage in securing the benefits of atmosphere control in the process of annealing.

Table 1

APPROXIMATE COMPOSITION OF SPECIAL ATMOSPHERES FOR MALLEABLE ANNEALING FURNACES

Type of Prepared Atmosphere Gas	*Gas Constituents in Percent*						
	O_2	CO_2	CO	H_2	CH_4	H_2O	N_2
DX gas, lean 40°F. Dew Point	0	10.5	1.5	1.2	0	0.8	86.0
DX gas, rich 40°F. Dew Point	0	5.0	10.5	12.5	0.5	0.8	70.7
Prepared nitrogen gas	0	0	1.5	1.2	0	0	97.3
CG gas Prod. at 1800°F.	0	0.2	20.5	36.0	3.8	0.5	39.0
XO gas	0	0	20.7	38.7	0.8	0	39.8
Charmo-gas Prod. at 2300°F.	0	0	34.7	2.5	0	0	62.8
Dissociated ammonia	0	0	0	75	0	0	25

(*Discussion for entire Symposium will be found on pages 133-148, inclusive.*)

Graphitization Symposium—IX

Some Effects of Hydrogen on the Time of Malleabilization

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Abstract

The paper summarizes the results of an experimental program undertaken in an effort to establish the influence of hydrogen in iron of malleable composition. A number of melts of quick-malleable type were made in a gas-fired, pot furnace, employing the following methods for varying the hydrogen content of the iron, (1) melting in the conventional manner, (2) using melting stock which had previously been annealed at suitable temperatures to drive off dissolved and occluded hydrogen, and (3) bubbling hydrogen through the melt before casting. The various treatments caused no significant differences in response to conventional annealing practices. Small specimens from the melts were then given a preliminary, low temperature heat treatment, covering the range from 300 to 1300°F., for the purpose of driving out dissolved or occluded hydrogen. The holding times at low temperature varied from ½ to 8 hours. Subsequent malleableizing anneals showed that considerable refinement of the temper carbon structure was effected by the low temperature treatment. The marked refinement in temper carbon structure, as a result of the low temperature pretreatment, was manifested in a greatly increased rate of malleabilization both in the first and second stages. The irons supersaturated with hydrogen were more responsive to the pretreatment than those produced in the usual manner.

1. The malleabilization of white cast iron is not a simple process, for progress in malleabilization is influenced by many variables in metal composition and in the malleableizing cycle.

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2. The annealer knows that first-stage malleabilization proceeds more rapidly as the maximum temperature of the cycle increases, and he takes advantage of this point by raising the temperature as high as possible without causing excessive losses from sagging of the castings and scaling of the annealing boxes. Second-stage graphitization, or pearlite decomposition, proceeds most rapidly when the castings are cooled at a rate just rapid enough to permit graphitization of the carbide as it is thrown out of solution. Throughout the cycle, close control of temperature must be maintained to produce an acceptable product at the most economical cost.

3. The influence of these factors on the time required for malleabilization is well known in the art. There are other factors, however, which produce rather marked effects but are less predictable; and, in many cases, the mechanisms by which they influence the malleabilization process are not so thoroughly understood. The rate of heating to the annealing temperature is one example of these latter factors. Smith and Palmer[1] and later Boegehold[2] have shown the importance of the speed of heating to the malleableizing temperature. Both investigations disclosed that heating commercial white irons slowly to the malleableizing temperature favored the formation of numerous small, closely-spaced temper carbon nodules, while rapid heating produced fewer particles but of a larger size. Heating the white irons rapidly to the malleableizing temperature was found also to decrease the rate at which the iron malleableized. This may be logically explained by the fact that the carbon in the matrix has to diffuse through a greater distance in order to reach, and to precipitate upon, the large, widely spaced nodules.

4. Crafts[3] states that a preliminary treatment of the white iron at a temperature between 200° and 750°F., for some period of time, preferably greater than 10 hours, materially increases the rate at which subsequent graphitization takes place and favors the formation of small temper carbon particles. The exact cause of the increased responsiveness is not known, but Crafts suggests that elimination of hydrogen from the iron may be at least partially responsible.

5. There is some evidence in the literature that moisture in contact with molten cast iron causes the formation of a more stable carbide and, hence, might influence the response to malleableizing.

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1 Superior numbers refer to bibliography at end of this paper.

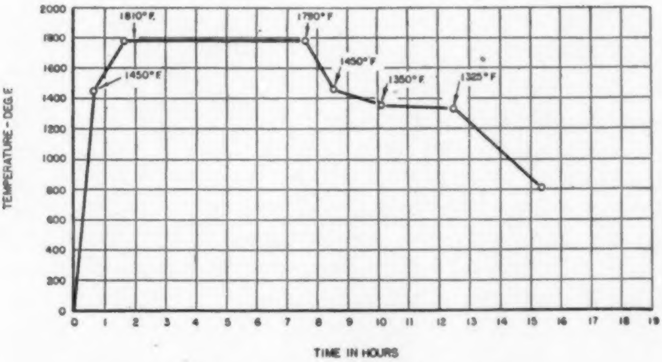

FIG. 1—ANNEALING CYCLE FOR MALLEABILIZATION.

The effect of moisture, in this respect, is usually ascribed to a higher hydrogen content in the iron. An experimental program was undertaken in an effort to establish the influence of hydrogen in iron of malleable composition. The results, summarized by Lorig[4], are presented in this paper.

EFFORTS TO DETERMINE THE EFFECT OF VARYING AMOUNTS OF HYDROGEN IN THE MELT

6. Rusty scrap in the melting stock and moisture in the cupola blast have been cited as possible sources of hydrogen and as the possible cause of variations in the temper carbon size of the resultant malleable iron; however, Schwartz and co-workers[5] state that hydrogen does not affect the nodule number in malleable iron. To investigate this question, a number of melts were made in a gas-air pot furnace, employing the following methods for varying the hydrogen content of the iron:

1. Melting in the conventional manner.
2. Using melting stock which had previously been annealed at suitable temperatures to drive off dissolved and occluded hydrogen.
3. Bubbling hydrogen through the melt before casting.

7. The melts were of the quick-malleable type, containing approximately 2.10 per cent carbon, 1.50 per cent silicon, 0.25 per cent manganese, 0.065 per cent sulphur, and 0.070 per cent phosphorus. The irons, made up as described, were subjected to a malleableizing cycle which was just sufficient to cause complete graphitization

for the compositions employed. A time-temperature curve representing the annealing cycle is shown in Fig. 1.

8. The various treatments caused no significant differences in response to annealing. These tests indicated either that hydrogen, within certain limits, had only a small effect upon the response to malleabilization or that the methods employed were not actually producing a difference in the hydrogen content of the final castings. Consideration of Sieverts'[6] diagram, Fig. 2, showing hydrogen solubility in pure iron, indicated that, because of the marked increase in solubility at the melting point, all three types of melts probably reached equilibrium with the surrounding atmosphere before being poured and, hence, actually contained approximately the same hydrogen content.

THE EFFECT OF REMOVING A PORTION OF THE HYDROGEN IN WHITE IRON CASTINGS ON MALLEABLEIZING TIME

9. In addition to the information given by Sieverts, Schwartz and co-workers[5] state that hydrogen can be expelled from white iron at temperatures below 750°F. Assuming, therefore, that the heats made up previously had reached equilibrium conditions during melting and that the final castings contained approximately the same hydrogen content, a series of experiments was planned in which the hydrogen was to be removed from the castings prior to malleableizing.

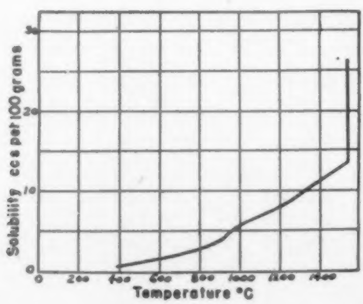

FIG. 2—SIEVERTS' DIAGRAM OF HYDROGEN SOLUBILITY IN PURE IRON AT DIFFERENT TEMPERATURES.

Materials Used

10. Irons completely saturated with hydrogen were produced by bubbling the gas through the molten iron, as shown in Fig. 3.

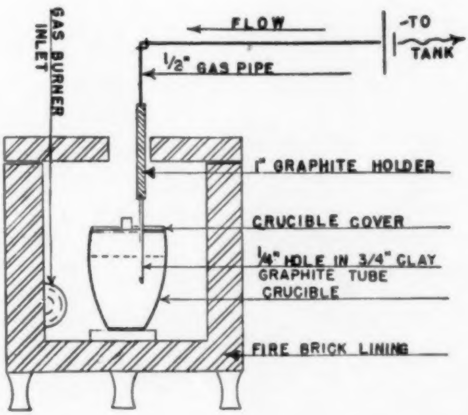

FIG. 3—GAS-FIRED, POT FURNACE WITH APPARATUS USED TO INTRODUCE GASES INTO THE MOLTEN IRON.

and casting immediately after the flow was stopped. For the purpose of comparison, another group of melts was made into which no hydrogen was introduced. Other irons were obtained from commercial sources in order that the effect of the treatment might be determined on materials not produced in the laboratory.

11. The compositions of the malleable irons employed in this investigation are listed in Table 1.

Low Temperature Treatments Prior to Malleableizing

12. Small specimens (½-in. rounds) from all the laboratory melts listed in Table 1, including both hydrogen-treated and un-

Table 1

CHEMICAL ANALYSIS OF THE MALLEABLE IRONS

	Composition, Per Cent				
Identification	*Carbon*	*Silicon*	*Manganese*	*Sulphur*	*Phosphorus*
FM-13	2.05	1.41	0.29	0.068	0.071
FM-18	2.10	1.62	0.33	0.08	0.110
FM-19	2.09	1.57	0.33	0.08	0.110
FM-20	2.11	1.57	0.32	0.07	0.109
FM-21	2.14	1.55	—	—	—
FM-17 (Hydrogen bubbled through melt)	1.88	1.62	0.32	0.067	0.076
FM-23 (Hydrogen bubbled through melt)	2.04	1.46	0.25	0.08	0.118
FM-24 (Hydrogen bubbled through melt)	1.98	1.42	—	—	—
FM-26 (Hydrogen bubbled through melt)	2.13	1.52	0.32	—	—
FM-27 (Hydrogen bubbled through melt)	2.18	1.60	0.34	—	—
Quick-Malleable Commercial	2.22	1.31	0.29	0.090	0.100
Quick-Malleable Commercial	2.10	1.55	0.25	—	—
Standard Malleable Commercial	2.50	1.00	0.30	—	—
Cupola Malleable Commercial	3.40	0.63	0.30	—	—

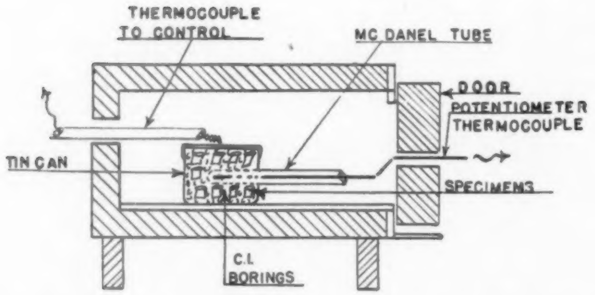

FIG. 4—THE ANNEALING FURNACE WITH THE ANNEALING BOX USED TO HOLD THE SPECIMENS.

treated melts, were given preliminary heat treatments covering the range between 600° and 1300°F., at 100°F. intervals, for the purpose of driving out dissolved or occluded hydrogen. A series of holding times, varying over the range from 2 to 8 hours, inclusive, was employed.

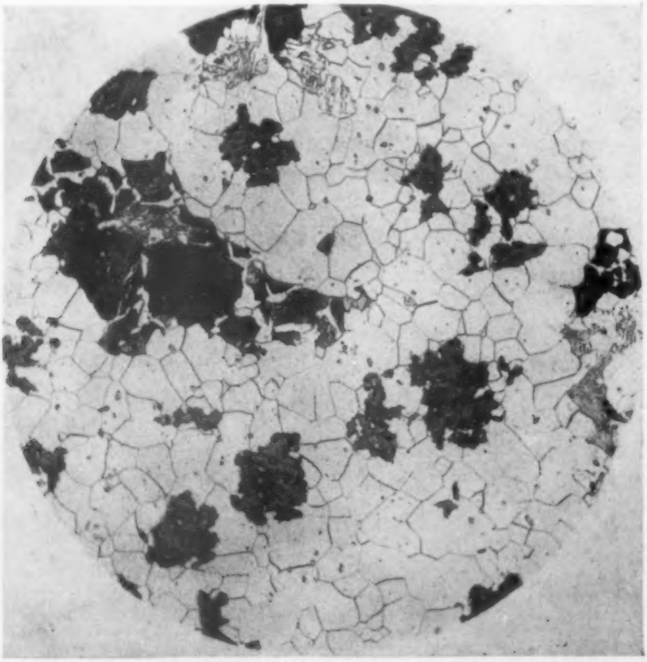

FIG. 5—STRUCTURE FROM MELT FM-17 (HYDROGEN TREATED) MALLEABLEIZED WITHOUT ANY PRELIMINARY TREATMENT. MAGNIFICATION, x100. SAME SPECIMEN SHOWN IN FIG. 7, TOP—RIGHT, AT LOW MAGNIFICATION.

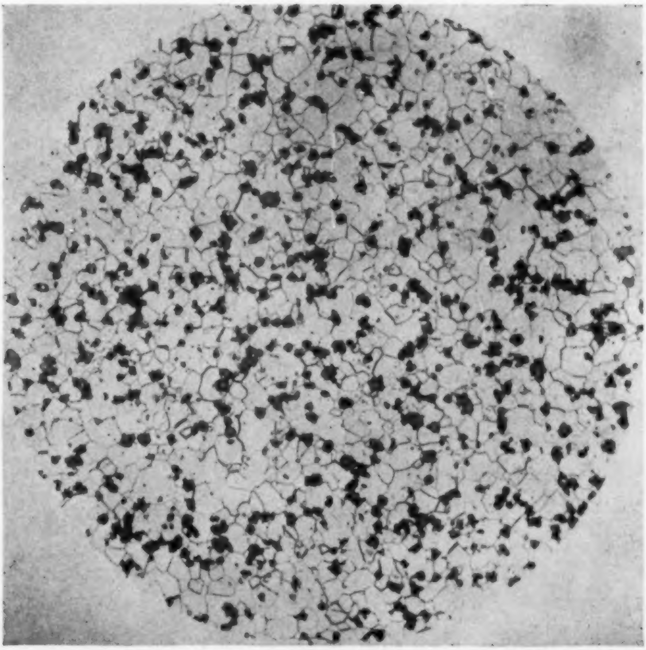

FIG. 6—STRUCTURE FROM MELT FM-17 MALLEABLEIZED AFTER HAVING BEEN GIVEN A PRELIMINARY TREATMENT AT 600°F. FOR 8 HRS. MAGNIFICATION, x100. SAME SPECIMEN SHOWN IN FIG. 8, TOP—RIGHT, AT LOW MAGNIFICATION.

13. After the low temperature treatment, these specimens, along with corresponding ones which were in the as-cast condition, were given the malleableizing treatment shown in Fig. 1. The small specimens were packed in a single container to insure that all received exactly the same treatment. The apparatus used in these malleableizing treatments is shown in Fig. 4.

14. The effect of the preliminary treatment upon the response of melt FM-17, Figs. 5 and 6, is typical of all the hydrogen treated irons. Figures 5 and 6, at 100 diameters, show detail; however, too small an area is covered to give fully representative views of the irons containing coarse graphite nodules. For comparing the different structures, photomicrographs at 20 diameters are shown in Figs. 7 and 8.

15. A comparison of Figs. 7—top left and 8—top left shows that considerable refinement of the temper carbon structure has been effected by the 600°F. treatment of the straight remelt. The

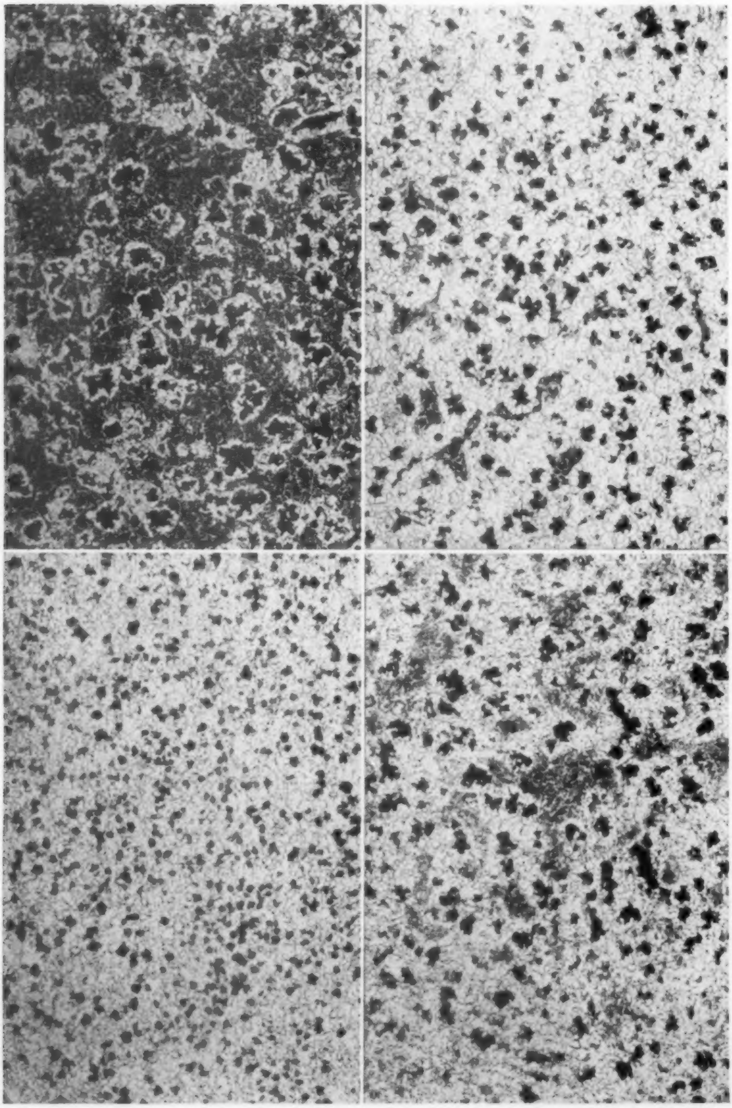

FIG. 7—EFFECT OF MALLEABLEIZING TREATMENT ON QUICK-MALLEABLEIZING IRON IN THE AS-CAST CONDITION WITH NO PRELIMINARY HEAT TREATMENT. TOP—LEFT, MELT FM-13, STRAIGHT REMELT. TOP—RIGHT, MELT FM-17, HYDROGEN BUBBLED THROUGH MELT. BOTTOM—LEFT, MELT FM-23, HYDROGEN-TREATED MELT. BOTTOM—RIGHT, MELT FM-24, HYDROGEN-TREATED MELT. COMPOSITIONS OF MELTS GIVEN IN TABLE 1 AND ANNEALING CYCLE IN FIG. 1. MAGNIFICATION, x20.

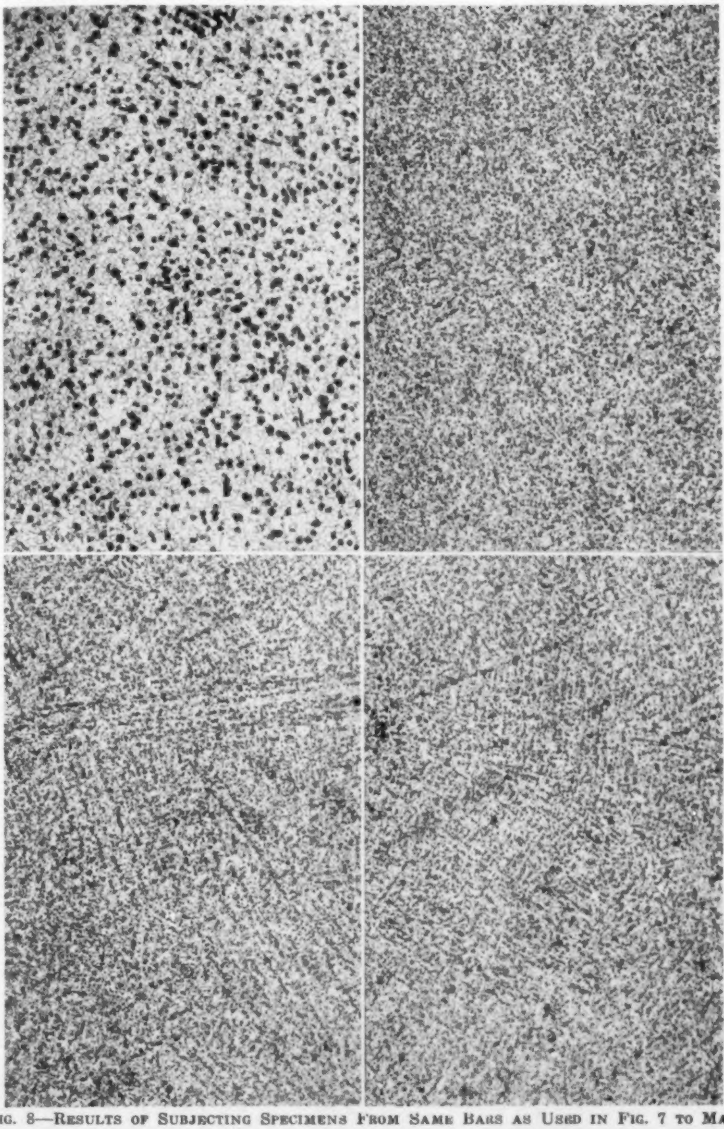

FIG. 8—RESULTS OF SUBJECTING SPECIMENS FROM SAME BARS AS USED IN FIG. 7 TO MALLEABLEIZING TREATMENT BUT SUBJECTING THE SPECIMENS TO A PRELIMINARY TREATMENT BY HOLDING THE SPECIMENS AT 600°F. FOR 8 HRS. TOP—LEFT, MELT FM-13. SAME MALLEABLEIZING TREATMENT AS IN TOP, LEFT, FIG. 7, EXCEPT FOR PRELIMINARY TREATMENT. TOP—RIGHT, MELT FM-17. SAME MALLEABLEIZING TREATMENT AS IN FIG. 7, TOP, RIGHT, EXCEPT FOR PRELIMINARY TREATMENT. BOTTOM—LEFT, MELT FM-23. SAME MALLEABLEIZING TREATMENT AS IN BOTTOM, LEFT, FIG. 7, EXCEPT FOR PRELIMINARY TREATMENT. BOTTOM—RIGHT, MELT FM-24. SAME MALLEABLEIZING TREATMENT AS IN FIG. 7, BOTTOM, RIGHT, EXCEPT FOR PRELIMINARY TREATMENT. COMPOSITION OF MELTS GIVEN IN TABLE 1 AND ANNEALING CYCLE IN FIG. 1. MAGNIFICATION, x20.

hydrogen treated irons, however, show an even greater response to the preliminary treatment.

16. The commercial, quick-malleable irons exhibited the same response as did the laboratory melts through which no hydrogen was passed. The preliminary low-temperature treatment produced some increase in the number of nodules when applied to standard malleable irons, but not to the same extent as in the case of the quick-malleable material. The cupola malleable, containing 3.40 per cent carbon, showed the least response of all.

Optimum Temperature Range and Holding Times for the Preliminary Heat Treatments

17. Specimens representing regular and hydrogen treated irons, melts FM-21 and FM-26, were given preliminary heat treatments at 300°, 600°, 800°, and 1100°F. Holding times at these various temperatures included intervals of ½, 1, 1½, 2, 4, and 8 hours. Other specimens from these same melts, but without any pretreatment, were included in the malleableizing anneal. Samples of all the specimens were prepared, after malleabilization, for metallographic examination.

18. A small band was drawn across the length of the ground glass of a metallographic camera and all the temper carbon nodules which fell within this band were counted. The number of spots on

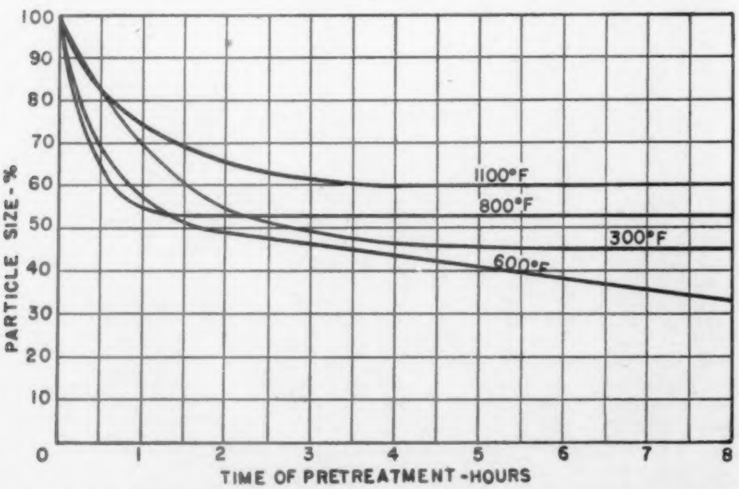

FIG. 9—EFFECT OF TIME AT DIFFERENT PREHEATING TEMPERATURES UPON THE TEMPER-CARBON NODULE SIZE FROM A MELT WHICH HAD NO GAS TREATMENT.

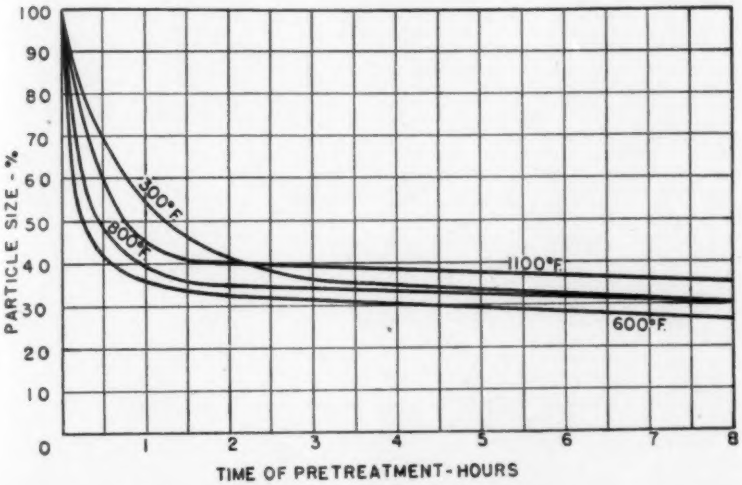

FIG. 10—EFFECT OF TIME AT DIFFERENT PREHEATING TEMPERATURES UPON THE TEMPER-CARBON NODULE SIZE FROM A MELT WHICH HAD HYDROGEN BUBBLED THROUGH IT BEFORE CASTING.

the untreated specimens from each melt was taken as unity and divided into the number of spots on the specimens which had been given preliminary pretreatments. The reciprocal of the resulting numbers was multiplied by 100 and these values were taken to be the relative size of the temper carbon spots in the pretreated specimens as compared with the size of nodules in specimens which had no treatment.

19. The results of these counts, showing the effect of time at different preheating temperatures, for regular and hydrogen treated irons, are shown in Figs. 9 and 10.

Influence of the Low Temperature Pretreatments on Time for First-Stage Malleabilization

20. Specimens, both with and without low temperature pretreatments, from melt FM-19 (regular melt) and FM-23 (hydrogen treated) were heated to 1790°F. in ½ hour, held for 5, 10, 15, and 30 min. periods, and quenched in water. The samples were subsequently drawn at 500°F. for the purpose of causing the martensite to etch brown so that the white iron carbide present could be readily distinguished.

21. Photomicrographs showing the gradual decomposition of

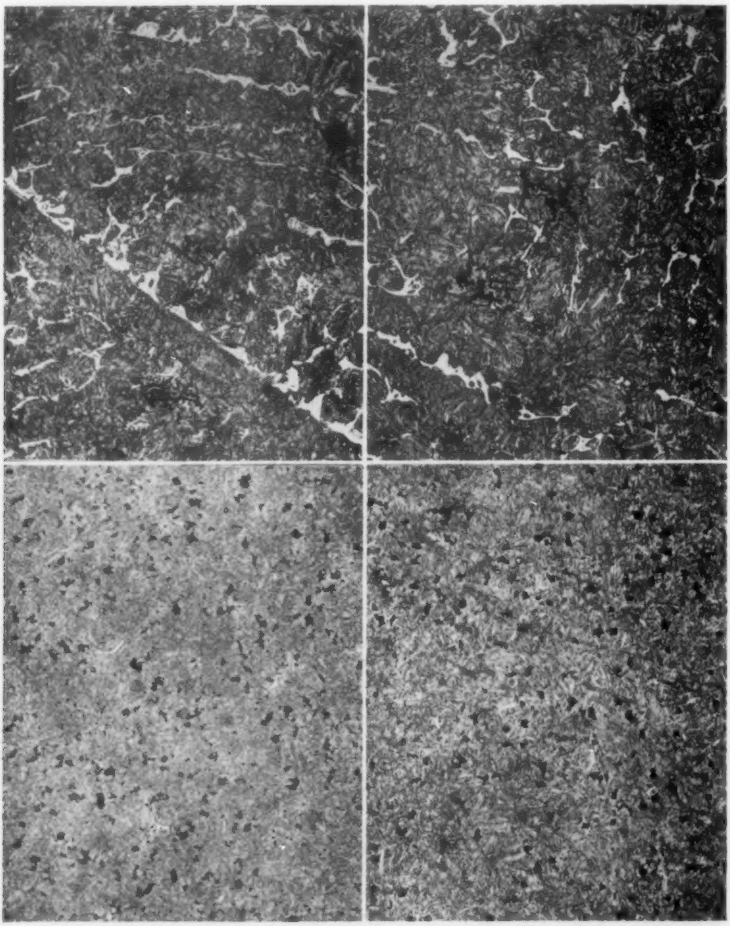

FIG. 11—TOP ROW—MELT FM-23 (HYDROGEN TREATED) WITH NO PRELIMINARY LOW TEMPERATURE TREATMENT. THESE PHOTOMICROGRAPHS SHOW THE AMOUNT OF GRAPHITIZATION UPON HEATING TO 1790°F. IN ½ HOUR AND HOLDING FOR THE TIME INTERVALS INDICATED BELOW. THE SPECIMENS WERE QUENCHED IN WATER FROM THE MAXIMUM ANNEALING TEMPERATURE AND SUBSEQUENTLY DRAWN AT 500°F. FOR THE PURPOSE OF DARKENING THE MARTENSITE. UPPER LEFT—5 MIN. UPPER RIGHT—10 MIN. BOTTOM ROW—SPECIMENS FROM SAME BARS FROM WHICH SPECIMENS WERE TAKEN FOR RESULTS PRODUCED IN TOP ROW BUT GIVEN THE PRELIMINARY LOW TEMPERATURE TREATMENT OF 8 HOURS AT 600°F. BOTTOM LEFT—5 MIN. HOLDING TIME. BOTTOM RIGHT—10 MIN. HOLDING TIME.

the free carbide in the hydrogen treated melt, with and without pretreatment, are included as Figs. 11 to 12. The untreated specimens show some undecomposed carbide after 15 min. at 1790°F., while those given a low temperature pretreatment are

completely graphitized after 5 min. The same trend was shown by the specimens from the melt which had no hydrogen treatment, but the difference was not quite so marked.

Effect of Preliminary Low-Temperature Treatments on Time Required for Complete Second-Stage Graphitization

22. Pretreated and as-cast specimens from the straight melt (FM-19) were completely graphitized by a first-stage anneal, cooled

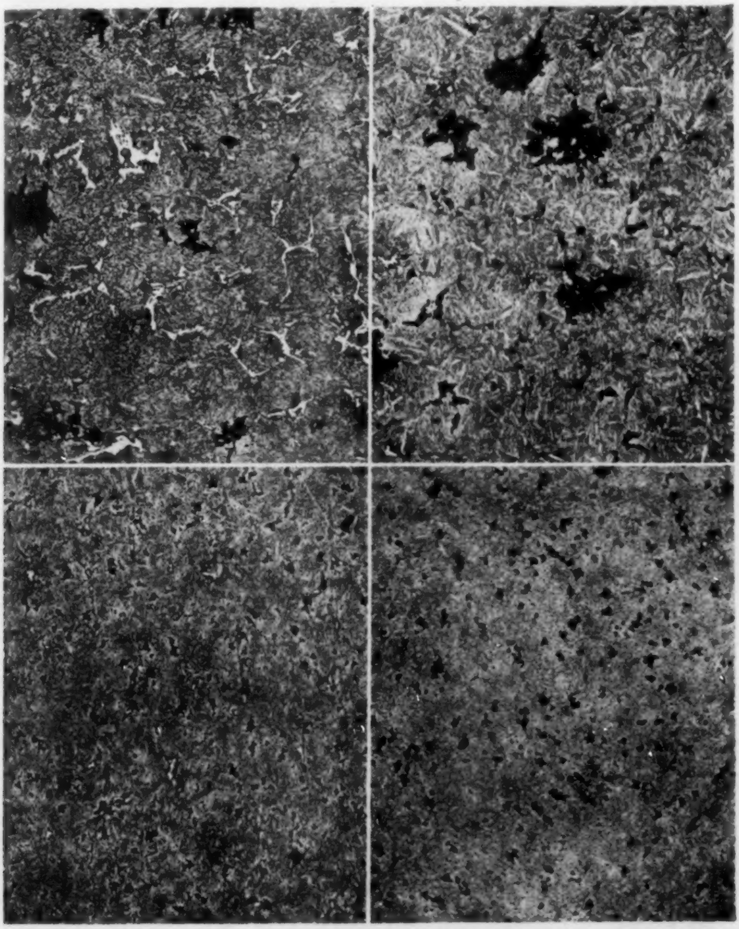

FIG. 12—RESULT OF SUBMITTING BARS FROM MELT FM-23 TO SAME TREATMENTS AS IN FIG. 11 BUT WITH LONGER HOLDING TIMES. TOP AND BOTTOM LEFT—15 MIN. TOP AND BOTTOM RIGHT—30 MIN.

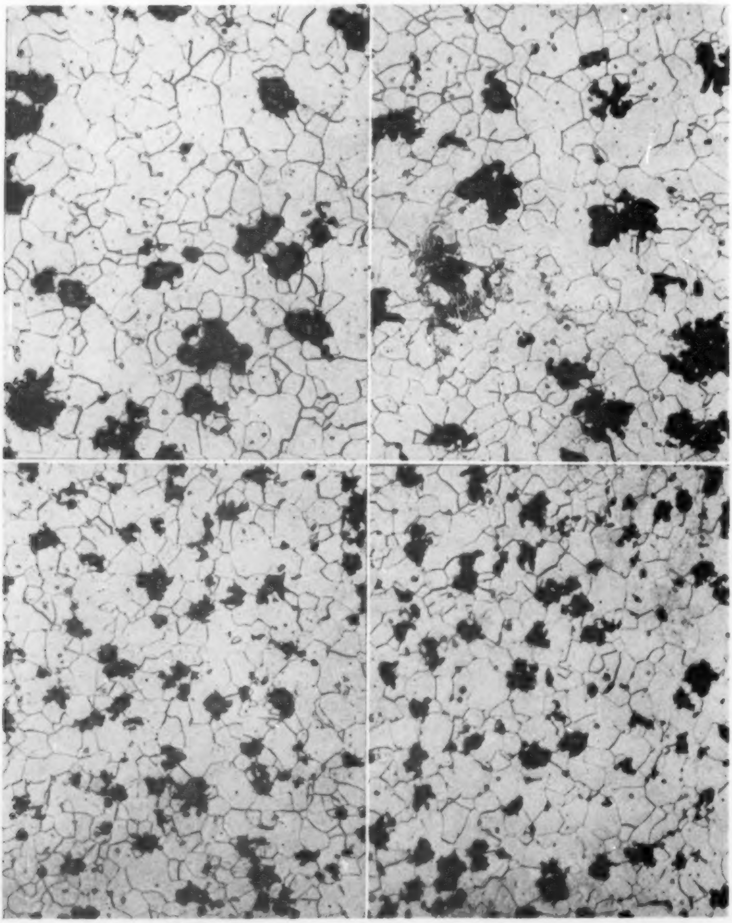

FIG. 13—STRUCTURES ARE FROM MELT FM-19 WHICH WAS A STRAIGHT-MELT AND SHOWED THE EFFECT OF COOLING RATE THROUGH THE 1450°-1200°F. INTERVAL ON SECOND-STAGE GRAPHITIZATION WITH NO GAS TREATMENT. THE SPECIMENS IN THE TOP ROW WERE MALLEABLEIZED WITHOUT LOW TEMPERATURE PRETREATMENT AND THOSE IN BOTTOM ROW, WITH THE PRETREATMENT. IN ALL CASES, MAGNIFICATION, x100. UPPER AND LOWER LEFT—COOLED AT A RATE OF 40°F. PER HOUR. UPPER AND LOWER RIGHT—COOLED AT A RATE OF 50°F. PER HOUR.

slowly to 1450°F., and then cooled through the temperature range of from 1450° to 1200°F. at increasing rates. A cooling rate of 300°F. per hour was required before any pearlite was retained in the pretreated irons while a cooling rate of 50°F. per hour caused some pearlite to be retained in the untreated specimens.

23. The hydrogen treated melt (FM-23) showed a still more marked response to pretreatment. A cooling rate of 900°F. per hour was necessary to retain pearlite in the pretreated specimens from this melt. Untreated specimens showed pearlite after a cooling rate of 50°F. per hour. Figures 13 to 16, inclusive, show the relationship between second-stage graphitization and cooling rate for the two melts (FM-19 and FM-23) in both the as-cast and the pretreated conditions.

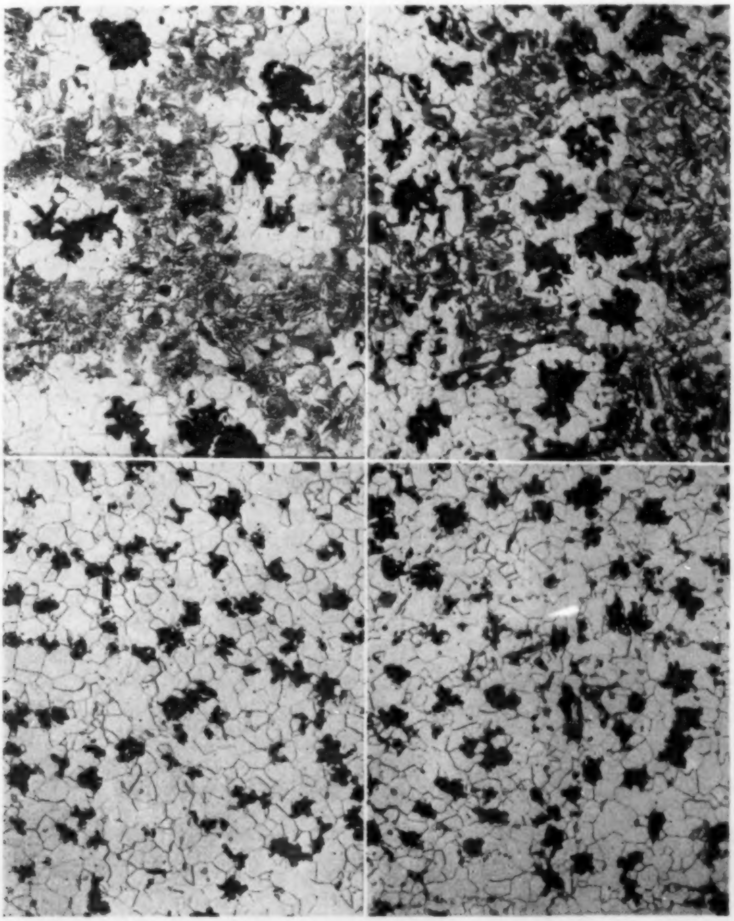

FIG. 14—STRUCTURES SHOWN ARE FROM MELT FM-19 UNDER SAME CONDITIONS AS IN FIG. 13 BUT WITH INCREASED COOLING RATES DURING THE 1450°—1200°F. INTERVAL. ALL MICROGRAPHS, MAGNIFICATION, x100. UPPER AND LOWER LEFT—COOLED AT A RATE OF 100°F. PER HOUR. UPPER AND LOWER RIGHT—COOLED AT A RATE OF 300°F. PER HOUR.

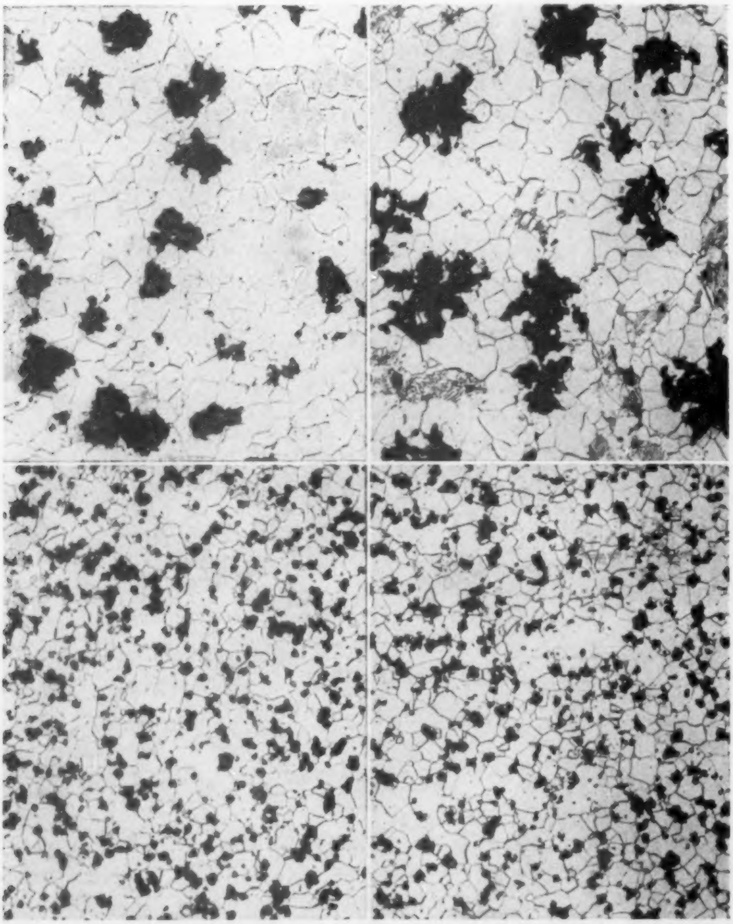

FIG. 15—MICROGRAPHS SHOWING THE EFFECT OF COOLING RATE THROUGH THE 1450°—1200°F. INTERVAL ON SECOND-STAGE GRAPHITIZATION. STRUCTURES SHOWN ARE FROM MELT FM-23 (HYDROGEN TREATED). THOSE IN THE TOP ROW ARE FROM SPECIMENS GIVEN NO PRETREATMENT BEFORE THE MALLEABLEIZING ANNEAL AND THOSE IN THE BOTTOM ROW WERE GIVEN SUCH TREATMENT. ALL PHOTOMICROGRAPHS AT x100. UPPER AND LOWER LEFT—COOLED AT A RATE OF 40°F. PER HOUR. UPPER AND LOWER RIGHT—COOLED AT A RATE OF 50°F. PER HOUR.

24. The so-called picture frame effect, namely a pearlite rim near the outside surface, was found to be more pronounced in the rapidly annealed pretreated specimens than that ordinarily found in malleable irons. Temper carbon nodules were larger also in this region of the castings.

DISCUSSION

25. In the case of the pretreated specimens, rapid decomposition of the carbide, in both the first and second stages of graphitization, may be explained by the presence of a greater number of temper carbon centers. The time required for carbon to diffuse and to deposit upon the temper carbon nodules is less than in the

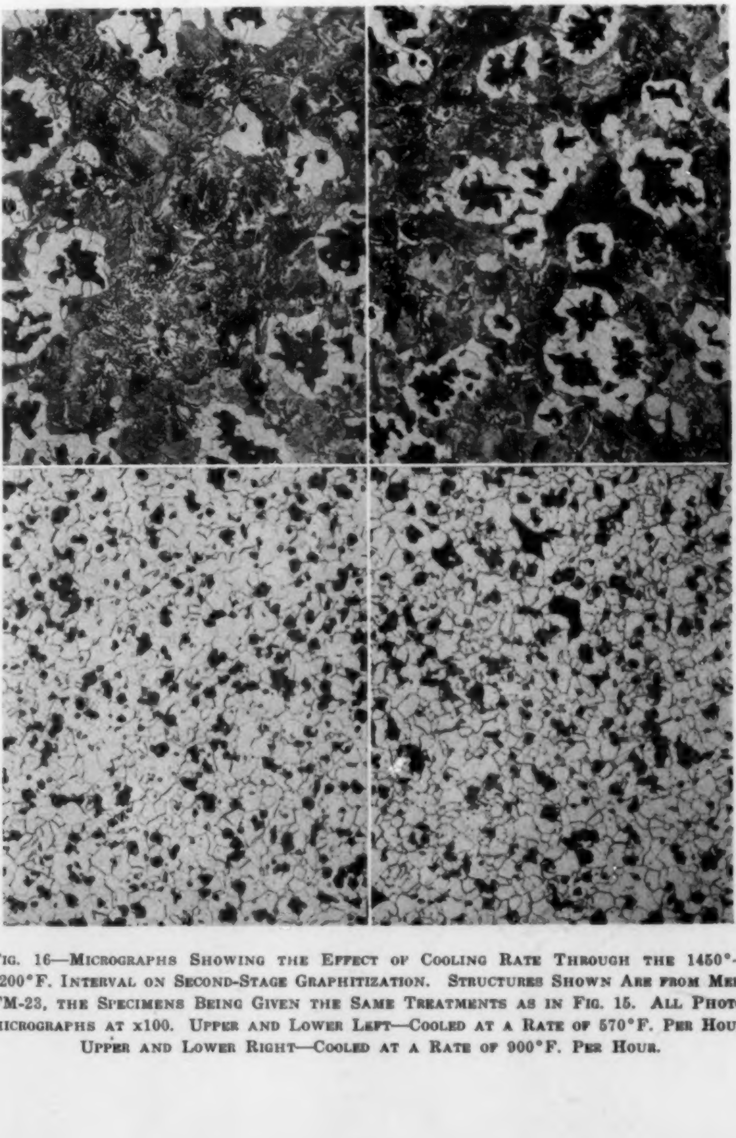

FIG. 16—MICROGRAPHS SHOWING THE EFFECT OF COOLING RATE THROUGH THE 1450°—1200°F. INTERVAL ON SECOND-STAGE GRAPHITIZATION. STRUCTURES SHOWN ARE FROM MELT FM-23, THE SPECIMENS BEING GIVEN THE SAME TREATMENTS AS IN FIG. 15. ALL PHOTOMICROGRAPHS AT x100. UPPER AND LOWER LEFT—COOLED AT A RATE OF 570°F. PER HOUR. UPPER AND LOWER RIGHT—COOLED AT A RATE OF 900°F. PER HOUR.

untreated specimens because of the shorter distance of travel through the matrix.

26. Since the hydrogen treatment, in the absence of a low temperature pretreatment, had only a small effect on either first- or second-stage graphitization (hydrogen treatment of the iron without a subsequent low-temperature pretreatment tended to produce somewhat coarser graphite nodules and to lengthen the graphitizing time in both stages) it cannot be assumed that the mere presence or absence of hydrogen has an important bearing upon the response to malleabilization. The hydrogen treated melts, however, invariably responded to low-temperature pretreatments to a greater degree than did the straight melts. This observation leads to the conclusion that there is something connected, not directly with the absence of hydrogen in the pretreated material, but with its escape during the long holding time at low temperatures that predisposes the iron to rapid malleabilization through the formation of a much greater number of nuclei.

27. At first, initial graphitization during the low temperature pretreatment was suspected of forming nuclei, although it was recognized that the most effective pretreating temperatures were far below the known graphitizing range. Pretreated specimens were carefully examined microscopically, however, for minute graphite particles previous to the malleabilization treatment, but not the slightest difference could be observed between the structure of as-cast and pretreated irons.

28. The tendency toward large, and consequently widely distributed nodules near the outside rim, is partly responsible for more retained pearlite. Reasoning from the hydrogen hypothesis, the larger graphite nodules would be explained by the fact that hydrogen, either dissolved or occluded near the surface, can more easily escape than that further toward the interior. Hydrogen originally located near the outside skin may escape during cooling from the casting temperature, or even at the beginning of the low temperature pretreatment, without producing the unique effect that it does at greater depth. The response to malleabilization in this outer region then would be expected to coincide with that of an iron which had not been given the low temperature pre-annealing treatment.

CONCLUSIONS

29. From this work, the following conclusions may be drawn:

1. White cast iron, especially that in the quick-malleable range of compositions, responds to both first- and second-stage malleabilization at a much faster rate after having been given a pretreatment in the neighborhood of 600°F.

2. Melts supersaturated with hydrogen are even more responsive to this pretreatment than those produced in the usual manner.

3. Faster malleabilization may be explained by the presence of a greater number of temper carbon nodules in the pretreated irons than in those annealed directly in the as-cast condition.

4. Smaller temper carbon nodules evidently originate from a nucleization effect of the low temperature pretreatment.

5. Nucleization is apparently associated with the escape of hydrogen, but the exact mechanism involved is still unknown.

ACKNOWLEDGMENT

30. The writers wish to express their appreciation to the Interlake Iron Corporation and The Youngstown Sheet and Tube Company, sponsors of the research investigation described above, for permission to publish this work.

BIBLIOGRAPHY

1. Smith, Cyril Stanley, and Palmer, Earl W., "*Some Effects of Copper in Malleable Iron,*" TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, Iron and Steel Division, vol. 116, pp. 363-385, (1935).

2. Boegehold, Alfred L., "*Some Unusual Aspects of Malleable Iron Melting,*" TRANSACTIONS, American Society for Metals, vol. 26, pp. 1084-1121, (1938).

3. Crafts, Walter, U. S. Patent No. 2,227,217, December 31, 1940.

4. Lorig, C. H., U. S. Patent No. 2,260,998, October 28, 1941.

5. Schwartz, H. A., Guiler, G. M., and Barnett, M. K., "*The Significance of Hydrogen in the Metallurgy of Malleable Cast Iron,*" TRANSACTIONS, American Society for Metals, vol. 28, pp. 811-829, (1940).

6. Sieverts, A., "*The Absorption of Gases in Metals,*" ZEITSCHRIFT FUR METALLKUNDE, vol. 21, p. 40, (1929).

(*Discussion for entire Symposium will be found on pages 133-148, inclusive.*)

Graphitization Symposium—X

Temperature Control of Graphitizing Furnaces

By J. H. Lansing*, Cleveland, Ohio

Abstract

In this paper, the author outlines temperature control in the malleable iron annealing operation. He first deals with the early efforts to control temperature and the reliance placed on the operator for securing a well-annealed product. He then discusses the use of thermocouples, millivoltmeter and potentiometer pyrometers, and both indicating and recorder type instruments for temperature control. He suggests additional methods of checking temperatures in malleable annealing furnaces, as well as emphasizing the temperature lag between the furnace temperature and the actual temperature of the castings in pots.

Early Temperature Control in Malleable Iron Annealing

1. In the early days of the malleable iron industry, the annealing foreman was an outstanding factor in determining whether the final product would be good, fair, or poor. Of course, some iron was sent to the annealing department which could not be properly annealed, due to faulty composition. But given an average product with which to start, the annealer could either turn out a good, tough product, or one quite deficient in all desirable properties.

2. He generally judged temperatures by eye and learned by experience that an oven which was not unduly rushed would produce the best castings. He classified his ovens according to results obtained and, therefore, had both "good" ovens and the others which either produced some underannealed castings, framed castings or ones lacking in adequate toughness. More often than not, he found that best results were obtained from the ovens that were slow to cool.

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* Shop Practice Engineer, Malleable Founders' Society.

Note: This paper was presented at a Malleable Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

3. Regular chemical analysis of the hard iron and the use of an indicating pyrometer came as steps which helped in the production of a good product. The experience of different plants was at variance, however, as some were positive that a certain number of hours at 1650°F. were necessary, whereas others were equally positive that 1500°F. was the proper "holding" temperature. This was due in large part to varying locations in which thermocouples were installed or inserted.

4. One of the early difficulties, or at least assumed difficulties, was with the "night fireman." If the iron was not up to standard, the suspicion was that the night fireman had not properly maintained the required temperatures. So the use of recording pyrometers not only helped insure a better product but reduced the mortality among night firemen.

5. As time went on, operators were advised that no purpose was being served by holding castings in the anneal after a temperature of 1200°F. had been reached. Some took this statement literally and opened their ovens when the oven thermocouple showed 1200°F. After the castings were cooled and samples tested. many were found to be "framed," so the operators decided that 1200°F. was too high a temperature. As a matter of fact, however, the 1200°F. temperature was suitable if it had been the temperature of the castings. But the 1200°F. had been the oven temperature at a rather low temperature location, and castings in pots containing packing in the center of the oven had been at a temperature probably in excess of 1300°F. In Fig. 1, the solid line charts the temperature recorded by a thermocouple inserted in the front of an oven at a height of 18-in. from the floor. The broken line charts the temperature recorded by a second thermocouple inserted in a pot containing castings at the same height and near to the first couple. It will be noted that when the oven couple shows a temperature of 1200°F., the pot couple is still slightly above 1300°F. Castings in pots in the center of the oven will be at even a higher temperature.

6. Experiences, such as this, demonstrated the necessity of either having a thermocouple in a pot with castings or of making allowance for a lag of some 100°F. or more in the cooling of the castings. To a comparable extent, there is a lag in the heating of the castings when the oven is being brought up to temperature. This fact makes the "time at temperature" approximately the

same, irrespective of whether the oven or pot temperature be used. The necessity of allowing for the lag arises, however, when the castings are being cooled or are held close to, but under, the critical range. Allowance must nevertheless be made for the lag in heating if the fire is being controlled by a pot-enclosed couple as otherwise excessive temperature may be reached and the life of the pots greatly reduced. The temperature lag, both in heating and cooling, is greater in pots containing packing than in ones containing castings only.

7. A further factor increasing the importance of temperature control in the malleable anneal, was an appreciation of the value of having the castings pass through the critical range slowly and of holding them just under the range for an extended period in lieu of a slow general cooling of the oven. Also the desire of many to reduce the time required for the anneal resulted in some use of electric and gas-fired, radiant-tube heated furnaces. In these types of equipment, with heating periods reduced to a minimum, close temperature control is essential. In batch ovens of this type, pyrometer thermocouples are needed at various locations to make certain that all parts of the oven attain the desired temperatures. In continuous ovens, zone temperatures are maintained and here again allowance must be made for any lag of the castings in attaining these temperatures. Importance also attaches to the rate of heating to the higher temperatures used in some of this equipment, as well as to a change in temperatures and periods, when material of high silicon content is annealed.

8. This outline of some of the early experience and later developments affecting temperature control in malleable iron annealing brings us to a consideration of the types of control equipment available.

TYPES OF TEMPERATURE CONTROL EQUIPMENT

Thermocouples

9. One manufacturer of temperature control equipment well defines a thermocouple as follows: "A thermocouple is a pair of wires (or other conductors) of different materials (usually metals), electrically connected at each end. In such a pair, an electromotive force is developed which is related to temperature difference between the two where the wires are joined. If temperature at one of these points, the reference junction, is held con-

stant (or provision is made to compensate for its variations) changes in e.m.f. represent changes in the temperature of the other, or measuring junction. In a typical thermocouple, two dissimilar wires (in insulators) join at one end to form a measuring junction, and terminate at the other in a connector or head, from which leadwires run to a measuring instrument. Usually the couple is enclosed in a metal or ceramic protecting tube."

10. Noble-metal thermocouples are used as standards for checking working couples, also, where temperatures are in excess of 2200°F.

11. For most uses, base-metal thermocouples of iron and constantan or chromel and alumel are used. They may be of the two wire type, with insulators, or in the case of iron-constantan, of the pipe-type. In this type a constantan wire, with insulators, is enclosed in an iron pipe and welded to the closed end. In general, the chromel-alumel is for use with an oxidizing atmosphere, the iron-constantan with a reducing atmosphere.

Millivoltmeter Pyrometers

12. The type of pyrometer in early use measured electrical current, thereby determining thermocouple electromotive force indirectly. In this case, it is essential that circuit resistance be held constant, so that consideration must be given to the effect of resistance changes due to switches and varying temperatures or lengths of leadwires. Some pyrometers of the millivoltmeter type have provision for automatic compensation for the effect of temperature change at the cold junction and for the temperature coefficient of the instrument.

Potentiometer Pyrometers

13. In this type of pyrometer, a constant flow of current is maintained through a slide wire resistance. To a sliding contact, an uncalibrated deflection galvanometer and a thermocouple are connected so that the e.m.f. of the couple opposes the potential difference between the slider and the zero point. The slider then moves until the thermocouple potential is balanced and the galvanometer will read zero. By means of the slider, the thermocouple hot junction temperature is indicated or recorded. Automatic compensation for cold junction temperature variations may be provided. The potentiometer method is generally considered to be the most accurate and reliable means for measuring the tem-

perature of a thermocouple.

PYROMETER EQUIPMENT IN GENERAL USE IN THE MALLEABLE INDUSTRY

Indicators

14. Indicators are in general use in the industry and serve the dual purpose of providing a guide for the fireman and a means by which the supervisor may check the temperatures of the various ovens. They are, of necessity, located in the annealing department where the fireman may have easy access to them.

15. In the case of plants where automatic recorders are not used, it is excellent practice to have the fireman hourly record the temperatures of all ovens on a record form maintained for that purpose. This makes more certain that the fireman will take the temperatures hourly and makes possible easy checking of his most recently recorded figures. A further advantage is that this record may be retained for checking purposes or may be used for the plotting of a curve of each oven run.

Recorders

16. In effecting proper control of temperatures, a permanent continuous record is of the utmost value. The possibly fallible human factor is thereby greatly reduced in importance and an accurate record is provided. This may be checked against the standard cycle and, if found to be at serious variance, points to the necessity of additional treatment prior to the unloading of the oven or to the necessity of close checking of the castings when dumped.

17. Instruments which record from 2 to 12 points are available. It is believed that the multiple point recorders well serve the purpose for the average malleable iron foundry. With an 8 point recorder, simultaneous record may be kept of two thermocouples on each of 4 ovens. In a similar manner, a 12 point recorder will, of course, take care of two couples on each of 6 ovens under fire at one time. The various points are recorded by numbers and it is not at all difficult to transfer them from the recorder chart to the type of record illustrated in Fig. 1. In some cases record of various points is made in different colors.

18. For convenient reference, comparison, and permanent record, a form approximately 18-in. long x 8-in. wide, with proper coordinate squares for plotting a curve of time and temperature,

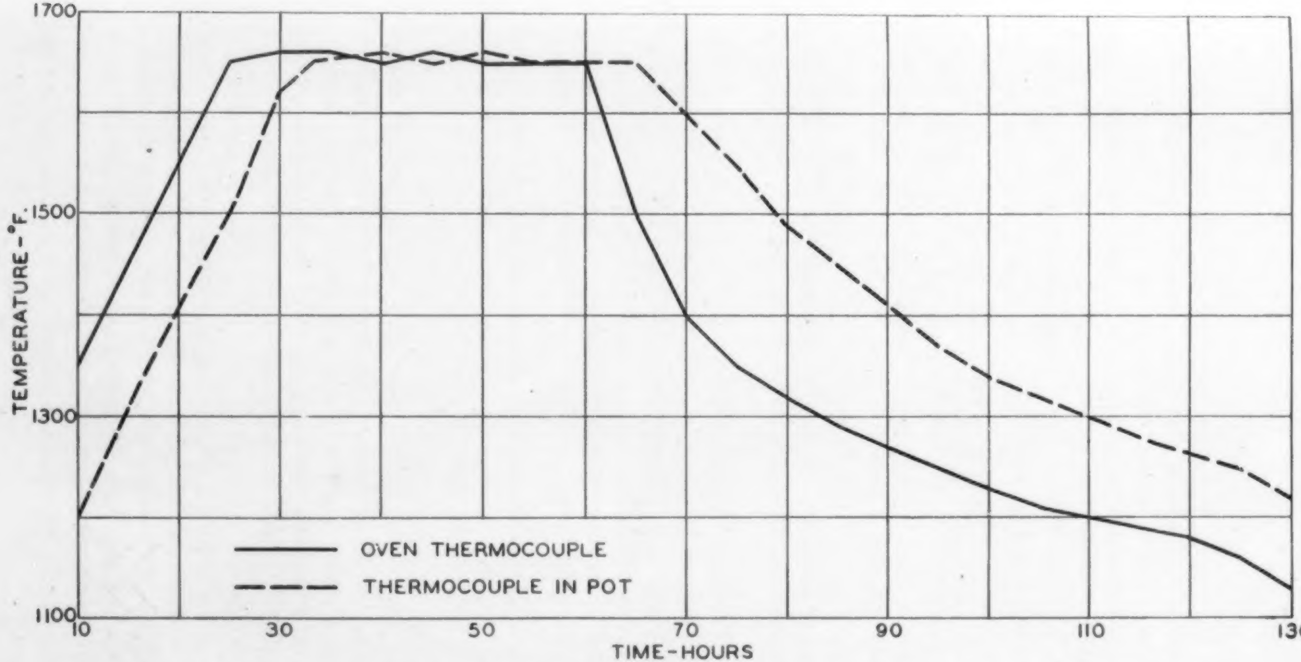

FIG. 1—ANNEALING RECORD OF POT-TYPE ANNEALING FURNACE SHOWING TEMPERATURE WITHIN FURNACE AND WITHIN POT.

OVEN RECORD

Date Fired	Jan. 2, 1940, *Hour*—1:00 A. M.,	*Date Dumped,*	Jan. 7, 1940
Hours to Temp.	25 oven 35 pot couple	*No. Tons*	19½
Hours at Temp.	35 oven 32 pot couple	*Test Bar Dates*	12/31/40 No. 2 Furnace
Hours 1350-1250	20 oven 26 pot couple	*Wedge Dates*	12/31/40 No. 2 Furnace
Total Hours	130	*Fractures*	O.K.
No. Stacks	24		

should be completed for each "run" of every oven. Plotting on this form from the regular recorder sheet daily, gives an additional check on operations and calls attention to any unusual variation. This form may also be easily and rapidly examined by the metallurgist or superintendent and serves as a basis for a check-back to ascertain the cause if improperly annealed castings are found. Test specimens from some definite heat should be in each oven and record made of that fact. A convenient form of the type described is shown in Fig. 1.

PROGRAM CONTROL

19. The practicability of program control of standard, batch-type, pot ovens, fired by oil, has been demonstrated in the case of at least one 10-oven installation. Potentiometer pyrometers are used on each oven and regulate both oil-flow and flue dampers. The fuel flow is regulated by means of a diaphragm-operated oil-and-air-proportioning valve and the dampers by diaphragm motor operators.

20. Safety devices, in case of power failure, air pressure drop or excessive temperature, so operate as to shut off the oil supply. Only in the case of one of these unusual failures is manual regulation required. At all other times, its necessity is completely eliminated with an increased certainty of uniform control and a reduction in operating cost.

CHECK OF COMPLETENESS OF ANNEAL IN LARGE OVENS

21. A means of checking the completeness of anneal in all sections of a large oven may be mentioned as of interest in connection with temperature control. To accomplish this, test wedges are placed in the bottom pot of each stack and are broken before the castings are removed from the dumping floor. To maintain a record for supervisory check, a box is provided with a slot properly located for each stack in the oven. As each wedge is broken, the butt end is placed, fracture up, in its proper slot. Thus, a board or box approximately 12-in. wide by 16-in. long will contain a complete record which may be checked at a glance. If there is any question as to the contents of any stack, the castings may be quickly segregated and work continued with the remainder of the oven's contents. This practice is not suggested as a substitute for temperature recording instruments but rather as a supplement to their use.

(*Discussion for entire Symposium will be found on pages 133-148, inclusive.*)

DISCUSSION*

Presiding: DR. H. A. SCHWARTZ, National Malleable & Steel Castings Co., Cleveland, O.

Co-Chairmen: D. P. FORBES, Gunite Foundries Corp., Rockford, Ill.
C. F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

E. G. MAHIN[1] (*written discussion of the paper on "The Principles of Graphitization," by H. A. Schwartz*): Almost the only criticism which I can offer in connection with this excellent discussion of principles has to do with what appears to be confusion regarding the actual mechanism of graphitization. Two views seem to have been somewhat intermixed, and I believe that this may serve to perpetuate a confusion which exists in the minds of many of those who are interested in malleable iron.

According to an explanation of long standing, often repeated in books, graphitization consists of a simple decomposition of cementite according to the equation:

$$Fe_3\,C \longrightarrow 3\,Fe + C$$

This is a simple and easy explanation, even though empirical, but I know of no convincing evidence that it has any direct relation to what happens when white iron is graphitized. If this reaction is responsible for the graphitizing action, one may wonder as to the role of silicon in the process.

Much has been said about the metastability, or the stability, of cementite, and many men have carried on investigations designed to throw light upon the question. It can scarcely be said that the matter has been decided, but, certainly, the supposed metastability of cementite is not great enough to concern the manufacturer or the user of steel. It is only when silicon is present in sufficiently high concentration that graphitization becomes an important consideration.

For making malleable castings, silicon must not be in as high concentration as in gray iron, otherwise graphitization at high temperatures cannot be prevented (without chilling the casting), with formation of flaky graphite. On the other hand, it must not be as low as in steel, or the casting will not graphitize at all.

The silicon is certainly not in the cementite phase except in minute concentration. Even an ordinary steel contains far more than enough silicon to saturate the cementite; therefore, the cementite will not contain any more, even in a high-silicon gray iron. Silicon is present in solid solution in the ferrite phase, at ordinary temperatures, and in austenite, at temperatures above A_1. (In hypoeutectoid steels, at temperatures between A_1 and A_3, silicon is in solution in both ferrite and austenite.) If, therefore, cementite contains all of the silicon it can dissolve, in both steels and cast irons (recalling that silicon is the most effective of all promoters of graphitization), why is it that steels may be subjected to all sorts of repeated heat treatments without graphitizing at

* The discussion which follows covers the papers presented in the Graphitization Symposium as a whole.
[1] University of Notre Dame, Notre Dame, Ind.

any temperature under melting, while cast irons graphitize so readily? The answer is to be found in the last paragraph of page 14 of the *Symposium on Malleable Iron Castings*, published jointly by the AMERICAN FOUNDRYMEN'S ASSOCIATION and the AMERICAN SOCIETY FOR TESTING MATERIALS. Briefly summarized, this amounts to a statement that at annealing temperatures, austenite precipitates carbon as graphite, silicon being the controlling element. This leaves the gamma iron unsaturated with respect to cementite which dissolves in accordance with the iron-carbon phase diagram. The two actions, precipitation of graphite and solution of cementite, proceed simultaneously until cementite has disappeared and, more slowly now, until practically complete graphitization is accomplished.

I believe that the author of the present paper subscribes to this view, as evidenced by his statement in paragraph 6. On the other hand, in paragraph one he writes of "the conversion of a compound of iron and carbon, called cementite, into free carbon (graphite) and iron." In paragraph 5 he says "It wishes to transform itself into iron and carbon ——," and in paragraph 9, "——the carbide, in its desire to break up ——."

These picturesque statements are obviously figurative embellishments of the paper and no objection could be made to them, were it not for the fact that they may serve to perpetuate the old idea of direct decomposition of iron carbide, and to leave some uncertainty as to just what is the author's understanding of the matter.

If the mechanism of graphitization of white iron be substantially as explained in the foregoing quotation, it might be objected that the graphitization is finished at a temperature below A_1, where the iron exists in the alpha form. But it is not quite correct to say that "carbon is not appreciably soluble below this temperature." This solubility has been tolerably well established as 0.035 per cent. It is also true, as already stated, that the silicon is still in solid solution in the ferrite phase, so that an action similar to that at higher temperatures may still be in operation. Such action might be expected to be extremely slow, but only a very minute amount of cementite should remain at this stage, to be redissolved in the alpha iron which has had its carbon expelled as graphite.

The author states (paragraph 11) that the graphite nodules always form at the surface of iron carbide. It might be expected that this would be the case, since it is only at the interfaces between cementite and austenite that solution of carbide may take place. However, it is doubtful whether the photomicrorgraph of Fig. 2 in the author's paper establishes this point very satisfactorily. Numerous graphite nodules appear to be embedded in pearlite grains and these grains, of course, were austenite at annealing temperature.

ORIEN SIMMONS[2] (*written discussion of Dr. Schwartz' paper*): Dr. Schwartz has given a clear concise description of the effects of the sev-

[2] Rose Polytechnic Institute, Terre Haute, Ind.

eral variables present in the malleableizing process. Would he care to extend this discussion to cover the essentials controlling the phenomena of "galvanizing embrittlement"?

DR. SCHWARTZ (*author's reply*): It appears that the author did not succeed in stating his concept of graphitization sufficiently clearly. Inasmuch as the alloy starts out to have its carbon present solely as Fe_3C and finishes the graphitization process with its carbon all in the free state, it seems incontrovertible that iron carbide has at some stage of the process been disassociated. Whether this disassociation takes place before the carbon goes into solution, while it is in solution, or when it is crystallizing out, nobody knows with any certainty. Certainly the author does not. It is not possible to explain the graphitizing process except by considering solution, disassociation, migration and crystallization, and the relative significance of these four in determining annealing rates is too complex a problem for inclusion in the present discussion. The author does not agree with Dr. Mahin that the metastability of cementite is not great enough to concern the manufacturer or the user of steel. The formation of free graphite in unalloyed tool steels has in the past been a serious problem to makers of small tools.

It has been shown by Austin and his co-workers that even the purest carbon alloys can graphitize. This point has been still more completely covered by Mehl, Wells and others. Graphitization thus cannot depend solely upon the presence of silicon, since it can take place in the lowest silicon alloys which have so far been made. That silicon favors the formation of graphite is of course indisputable. So far as the author knows, there is no explanation of this phenomenon, and it does not seem possible to deduce a mechanism of graphitization from the fact that silicon favors that process. It is doubtful whether there is any convincing evidence as to how soluble silicon may be in cementite.

It may not be amiss here to refer to the fact that if there be but one type of solid solution of carbon in gamma iron, then if cementite is metastable, gamma iron saturated with respect to graphite at a given temperature must contain less carbon than gamma iron saturated with respect to cementite. If cementite be stable, the reverse must be true.

Any explanation of graphitization based on the free energy of formation of cementite must therefore lead to the same conclusions as as explanation based on relative solubilities, if there be but one type of solution. If there be two types of solution, then this does not necessarily follow, although it might follow.

It seems to lead us far from the subject of this symposium to reply to Mr. Simmons' question. The facts of galvanized embrittlement are pretty well understood. Among these facts is the conclusion that silicon and phosphorus promote this effect. The phenomenon is one which suggests the occurrence and removal of grain boundary inclusions. Some authors seem to consider these inclusions as carbides, some suggest nitrides. The observations with regard to silicon and phosphorus suggest compounds of these elements. None of these inclusions has ever been seen in the writer's laboratory. To the best of our knowledge, nobody else has seen them, but only deduced their presence by reasoning. Under

the circumstances, it is scarcely possible to accept without reservation any hypothesis about the phenomenon which might be absent.

MR. SIMMONS (*written discussion of the paper on "The Effect of Composition on the Annealing of White Cast Iron," by W. D. McMillan*): It is noted that the nodule count seems to decrease with length of holding time at temperature. I wish to concur in this observation and to add that the same characteristic seems to be possessed by malleable iron which has been prequenched from the gamma region previous to first stage. The tests noted were on duplexed air-furnace iron with 1.30 per cent Si and 2.50 per cent C.

Due to the decrease in nodule count it would be expected that prolonging first stage should have a tendency to also prolong second stage as the diffusion distance would be increased. Now Dr. Schwartz in paragraph 10 of the "*Principles of Graphitization*" (pp. 1-23) states that "the number of carbon nodules does not change materially during the graphitizing process." Perhaps this anomaly is due to the difference in irons examined.

In work done at Rose Polytechnic Institute, a test bar was cut into several portions and all were placed in a furnace at temperature. Then at successive intervals of time a piece was removed and quenched and a nodule count was made. Perhaps this observation of decrease could be coincidence though it was noted on five different sets of test pieces from the same heat which had been prequenched from different temperatures.

A. R. ELSEA[3] (*written discussion of Mr. McMillan's paper*): The author brought out a point that seems to be contrary to the results we obtained at Battelle Memorial Institute during a study of the malleableizing cycles for white cast iron. In his paper, Mr. McMillan shows results indicating that the temper carbon nodule number decreases with extended holding time at the first stage graphitizing temperatures.

I would like to present the following information which has a bearing on the point in question:

Specimens of white cast iron (2.56 per cent carbon, 1.02 per cent silicon, 0.32 per cent manganese, 0.10 per cent phosphorus, and 0.072 per cent sulphur) cut from identical bars cast from the same melt were given first and second stage malleableizing treatments to determine the rate of graphitization for various cycles. Figures 1-D and 2-D of this discussion are representative micrographs of two specimens that were heated to 1600°F. in 30 minutes, held 18 and 45 hours, respectively, and furnace cooled at 34°F. per hour and 10°F. per hour, respectively. There is very little difference in nodule size or distribution. A nodule count consisting of the average for five fields was 33 nodules for the iron held 18 hours and 34 nodules for the iron held 45 hours. Similar results were found for specimens held at 1700°F. for various lengths of time. The cooling rate, of course, has no effect on nodule distribution and only affects the size insofar as a rapidly cooled malleable iron will have more combined carbon in the matrix in the form of pearlite.

[3] Battelle Memorial Institute, Columbus, O.

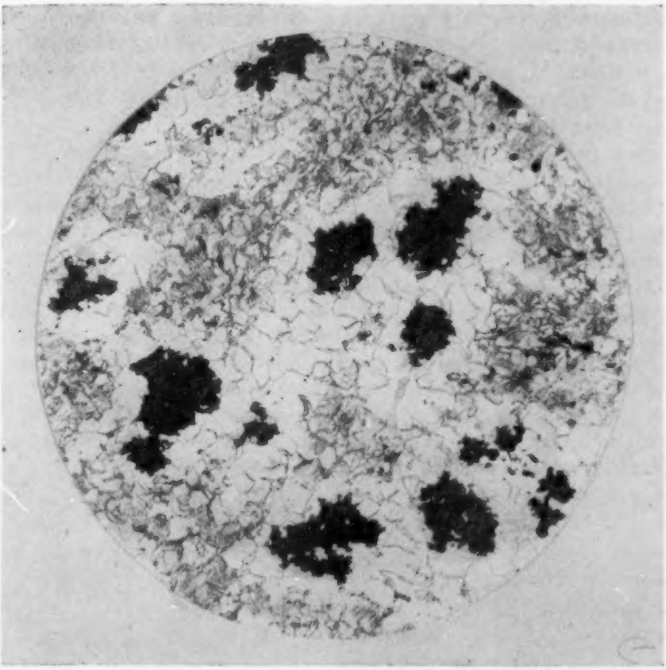

FIG. 1-D—SPECIMEN (2.56 PER CENT CARBON, 1.02 PER CENT SILICON, 0.32 PER CENT MANGANESE, 0.10 PER CENT PHOSPHORUS AND 0.072 PER CENT SULPHUR) HELD 18 HOURS AT 1600°F. AND COOLED AT 34°F. PER HOUR. NITAL ETCH. x100.

There is no question as to whether the dark areas in Figs. 1-D and 2-D are graphite nodules or polishing pits, since the graphite has retained its gray color. The composition of these specimens compares favorably with Mr. McMillan's iron B-1 which contains 1.02 per cent silicon, 2.62 per cent carbon, and 0.29 per cent manganese.

MR. MCMILLAN (*author's reply*): With regard to Mr. Elsea's written discussion, the photomicrographs of the iron in question show a count of 11 or 12. The magnification shown is 100. In the text, the count is shown as 33 and 34 respectively for the iron held 18 hours and 45 hours.

I assume that the count was made at a magnification of about 35 diameters. From our experience, a count of 11 or 12 at 100 magnification is normal for iron heated rapidly to the annealing temperature. Our experience, too, indicates that, where the count is on the order of 5 to 15, there is not much, if any, change in the number or size of nodule with prolonged heating. It may be that if the iron had been examined after 9 hours at 1600°F. the count might have been a little higher.

I appreciate the interest Mr. Elsea has shown and hope this reply may offer a plausible explanation of the condition he has brought out.

MR. SIMMONS (*written discussion of the paper on "Graphitization of Arrested Anneal Malleable Iron," by D. P. Forbes*): I should like to ask the author if the pearlitic malleables produced in this manner are subject to "galvanizing embrittlement."

MR. FORBES (author's reply): So far as I know no data are available as to the susceptibility of pearlitic malleables to galvanizing embrittlement. In completely annealed malleable iron, embrittlement is apt to occur in the presence of silicon above 1.10 per cent and phosphorus above 0.20 per cent, particularly if during the annealing process the castings are cooled slowly through the temperature range below the critical and if they are cooled rapidly from a temperature of approximately 850°F. Embrittlement can be avoided if the castings are cooled rapidly from about 1250°F. by quenching in air or a liquid. Some authors attribute this embrittlement to age hardening of the ferrite by precipitation of carbide from solid solution in ferrite at sub-critical temperatures. This causes strengthening of the ferrite grains, which thereby reduces their ductility when subjected to shock, with the result that fracture occurs in the weaker grain boundaries.

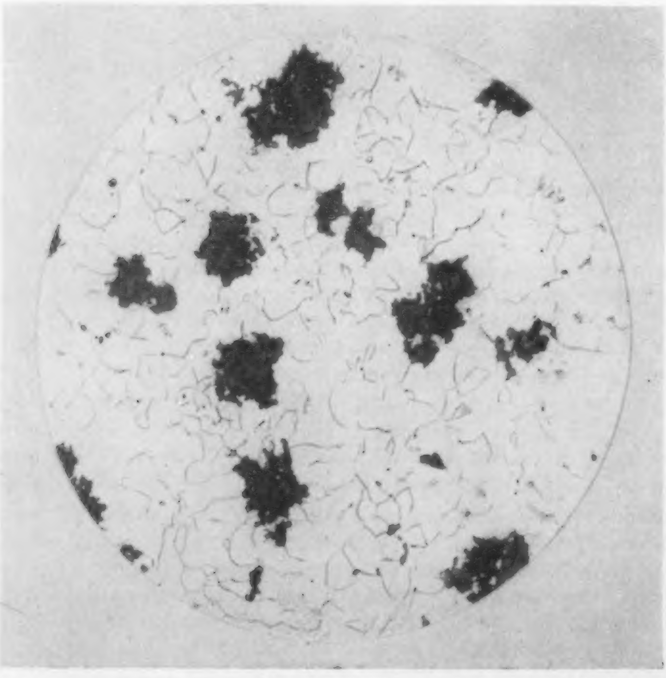

FIG. 2-D—SPECIMEN (2.56 PER CENT CARBON, 1.02 PER CENT SILICON, 0.32 PER CENT MANGANESE, 0.10 PER CENT PHOSPHORUS AND 0.072 PER CENT SULPHUR) HELD 45 HOURS AT 1600°F. AND COOLED AT 10°F. PER HOUR. NITAL ETCH. x100.

Nearly all of the processes for producing pearlitic malleable include rapid cooling through the temperature range favorable to embrittlement and it is, therefore, doubtful if galvanizing embrittlement would occur. So far as I know there have been no cases of embrittlement encountered by manufacturers which would further indicate galvanizing embrittlement is not a problem with malleables of the pearlitic type.

MR. SIMMONS (*written discussion of paper on "Some Effects of Hydrogen on the Time of Malleabilization," by C. H. Lorig and M. L. Samuels*): In some work done at Rose Polytechnic Institute on the prequenching of white cast iron, it was found that the finer distribution of graphite obtained by this treatment was associated with a great decrease in ductility though the tensile strength did not seem to be altered. Was the iron produced by the authors' treatment noticeably different in physical properties as well as in microstructure, and was any correlation noticed between the structure and the physical properties.

MESSRS. LORIG and SAMUELS (*authors' reply*): We were pleased to have the comments by Mr. Simmons on properties of malleable as affected by the prequenching treatment. In conduct of the work described in the paper, no effort was made to study the physical properties of the irons, hence we were not able to correlate the structure with physical properties.

DR. MAHIN: May I ask what material is used for the charcoal container in the Charmo gas method mentioned in Mr. Cowan's paper? Is it a chrome-nickel alloy?

MR. COWAN: I think it is a 35 nickel-15 chromium alloy.

MEMBER: The cycle of 72 hours mentioned by Mr. Jaeschke, is that in and out in 72 hours?

MR. JAESCHKE: Yes, I believe it is. I might add three hours for loading and unloading which brings it to 75 hours. Actually they have done it in considerably less time than that, but the 72 hours is a safe figure to mention.

MEMBER: Is that a normal silicon?

MR. JAESCHKE: Yes. It is duplexmalleable. It is in the neighborhood of 1.10 per cent silicon.

MEMBER: Are they using packing?

MR. JAESCHKE: No.

MEMBER: What tonnage is used?

MR. JAESCHKE: Those particular ovens have 12 to 16 tons capacity.

MEMBER: What is the carbon content of that 1.10 per cent silicon?

MR. JAESCHKE: In the neighborhood of 2.45 per cent.

MEMBER: And the 35018 specification?

MR. JAESCHKE: Yes.

MR. COWAN: In the combination gas-electric furnace shown by Mr. Cherry, in Fig. 4 of his paper, what is meant by radiant gas burner?

MR. CHERRY: The radiant type of burner used is one where there is no flame in contact with the castings but the products of combustion are drawn down through the charge.

MR. COWAN: The products of combustion are in contact with the charge?

MR. CHERRY: Yes.

MEMBER: Did I understand that there are 24 containers to 8000 lb. of work in your batch-type furnace?

MR. CHERRY: There are 16 containers per charge, loading 8000 lb. net of castings per charge, with the containers weighing approximately 2200 lb.

MEMBER: About 4:1?

MR. CHERRY: Yes, 4 lb. of castings to 1.1 lb. of containers.

MR. MCMILLAN: In connection with Mr. Anderson's paper, did he take out the muffle in that kiln? It is direct-fired after it is shortened?

MR. HARRIS: Just in the front end. The muffle is still there. It was more of a preheating chamber than anything else. I guess there was a distance of about 50 ft. before we came to our first burner.

MR. MCMILLAN: We had a problem of having a little more tonnage than we could handle in one kiln, so we put a door in the second kiln, using the burnered end as a periodic oven. We put the door in the kiln so there were 27 cars in the heating zone. We did not change any burners to any great extent, nor did we try to burner the kiln so that we could heat up all 27 cars. We simply allowed 18 of them to come up to temperature. We pushed in 27 cars and 18 of them were considered as having gone through a satisfactory cycle. We allowed them to come up to 1700°F. and held them 24 hours, allowed them to cool in that portion of the kiln, and then opened the door and pushed them out into the other half of the kiln. In that way we were able to get a five-day cycle and about 72 tons every five days which helped considerably when we had no other way of getting it. It would have meant buying a good many more cars and pots in order to fill up the kiln which required 62 cars. It was a way out and it worked out very satisfactorily.

MR. HARRIS: Did I understand correctly that you used one-half of your oven as a zone for heating for your first stage and then brought the cars out of that half and put them into the other half and used that for your cooling zone or your second stage?

MR. MCMILLAN: No, the second stage was made in the same zone without moving the cars. We just put in a door in there 27 cars down and called that a periodic oven.

MR. COWAN: I would like to discuss Dr. Lorig's paper. This matter of a pretreatment, a preliminary low temperature treatment of hard iron previous to annealing, is one that the laboratories with which I have been connected have been studying. We have been working on it for a long time. It may be interesting to follow through the development of that idea. In some work going through the laboratory on case-hardening of metals, we were using carbon and nitrogen, and we found that those elements were friendly enemies. That is, the nitrogen seemed to resist the carbon and there was an effect there that seemed to indicate that it might have something to do with this matter of nucleization in malleableizing hard iron. The question has always been up as to what it is that causes this nucleization, and we just got the hunch that if we could

put nitrogen into the metal maybe the nitrogen would serve as a nuclei for carbon precipitation, and the interesting thing was that we did and it did. We nitrided a piece of hard iron, went through the usual nitriding operation, and when that material was annealed, we were very much pleased to find that it annealed in a hurry, and had a very fine division of graphite. We had apparently brought about an increase in the number of nuclei for carbon precipitation.

The only drawback was that nitriding is a long-time operation. We tried introducing nitrogen into the melt, and, when we did it that way, we found that instead of increasing the number of nuclei or the rate of graphitization, it really retarded it. We went back and treated at a low temperature and found we got that same effect which Dr. Lorig has noted in his paper. We studied a great many different commercial metals. Our concepts were research laboratory concepts carried out in shop practice. We got metal from a number of different foundries and investigated them under a number of different conditions.

The usual procedure was to heat this metal in a lead pot and, heating it in that way, we avoided the atmosphere effects and were able to hold for a specified time, then remove from a lead pot and cool in a hurry. We found that by heating at a low, about 600°F., temperature, we got a certain effect, and by heating at a higher temperature, about 1100 or 1300°F., we got a different effect which decreased. The greatest number of nuclei were produced by heating at the lowest temperature.

Our preliminary work had been done in a lead pot. When we did it in an air muffle furnace, we did not get the same effect. Cooling in the furnace rather than cooling in the air gave us a nucleization effect that was an entirely different thing. We could heat at 900°F. in a lead pot, take the A.S.T.M. bar out and cool it in the air and that would give us a very fine nucleization. Heating it in and cooling it with the furnace, we got an entirely different effect, so that the effect is connected up, not only with the hydrogen content of the metal, but with some other effect that is there.

I did not notice whether or not Dr. Lorig had made any hydrogen determinations. Has it been proven that this is really due to hydrogen or is it due to some other effect? I remember that Dr. R. Schneidewind of the University of Michigan suggested an iron-silicon alloy, a silicide of some form or other, which is changed from one form into another, that serves as a nucleus for the carbon precipitation.

In connection with other work that has been done, it has been shown that hydrogen is not eliminated at these temperatures. It has been shown, in fact, that, contrary to most gases, hydrogen is absorbed, and that is a very important factor in connection with the annealing of sheet steel. Why is it that sheet steel strip, when annealed in batch annealing, is a different metal from that which is normalized? A great deal of time has been spent in investigating this shelf-area, the second-stage annealing, the rate of cooling, and if it comes down actually to the matter of the elimination of hydrogen, the hydrogen is not eliminated at those temperatures in an atmosphere if it contains hydrogen. On the other hand, it tends to be absorbed, giving a hydrogen effect.

Another very interesting thing is that as nucleization is increased, the physical properties of the metal go down, the tensile drops off and elongation drops off. Another very interesting thing is that manganese has a tremendous effect. That is, excess manganese over the manganese-sulphide ratio has a tremendous effect on the results.

DR. LORIG: I will admit, offhand, that our concept of the mechanism involved in pretreatment is rather visionary. We did not attempt to make any hydrogen determinations. It is a very difficult determination as anyone knows. I think Dr. Schwartz has had experience with it and has worked out a satisfactory method for determining hydrogen in iron. We have two sets of apparatus available which can be used. One employs the vacuum fusion method and the other the combustion method. We are skeptical of results by the vacuum fusion method, and are not far enough along with the combustion method to be sure of its results.

Our concept suggests that carbon is tied up with hydrogen to some extent. There is that possibility that hydrogen in iron exists, in part, as methane. Thermodynamically, this seems possible. It is also possible that methane decomposes at the low pretreating temperatures of about 600°F. It would then be possible for very minute nuclei of carbon to deposit somewhere in the iron during the pretreatment, probably at disjunctions or rifts in the metal. That may account for the increased number of graphite nuclei in the iron as a result of the low temperature pretreatment. The greater number of graphite nuclei would speed up the rate at which the iron graphitizes.

As to the effect of nitrogen mentioned by Mr. Cowan, it is very interesting. It may be that when molten metal is treated with nitrogen, the amount of hydrogen in the melt is decreased, and, therefore, the iron would not respond to pretreatment as would the iron without the nitrogen treatment.

We tried to introduce hydrogen into solid white iron by electrolysis to see if the iron so treated would also show the marked effect of hydrogen. Our experience was that this method for introducing hydrogen had no effect on the rate of malleabilization, the iron behaving in the same manner as iron not subjected to electrolysis. This indicated to us that hydrogen must be in another form in the iron than occluded hydrogen, when it is added to the melt. From this it appears that hydrogen may exist partly as methane which subsequently is reduced to carbon atoms and hydrogen later in the pretreatment.

CO-CHAIRMAN FORBES: In the pretreatment at 600°F., did you cool to room temperature at the end of it, or did you continue on up to the first graphitizing?

DR. LORIG: In all our tests described in the paper, we cooled to room temperature prior to heating to the malleableizing temperatures. However, we did try some in which we heated to the pretreatment temperatures and then raised up to the annealing temperature. There was no difference in the effect.

M. E. MCKINNEY[4]: In making some tests on this nuclei reduction size,

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we found out, especially in one case, that a heat that is definitely oxidized will not respond at all to pretreatment, so I am wondering whether the hydrogen treatment has been a deoxidization of some kind and whether any kind of deoxidization will not give the same result.

CHAIRMAN SCHWARTZ: When I read Dr. Lorig's paper, I wondered how much of this effect had to do with the mechanical sweeping effect of hydrogen through liquid metal. I was about to suggest the substitution of an inert gas whether it was argon or nitrogen. If somebody would duplicate that we might have another sidelight on it.

As to the determination of hydrogen, the direct combustion method which we have used has this much to recommend it, it is easier to do than the vacuum fusion method. It checks the average value with the Bureau of Standards hydrogen values in five or six steels, and it goes up and down intelligently with the times when you think hydrogen ought to go in and ought not to go in. To that extent the combustion method does indicate something. Heat treatments somewhere from 392 to 572°F. up to 1112 or 1292°F. do actually, by analysis, remove hydrogen. The data are in the paper * given before the A.S.M. two years ago, so that we do know, as far as that method goes, hydrogen is removed, and when work was done on these low temperature treatments, they actually pumped off the hydrogen and determined that it was hydrogen. It may have been methane when it was in the iron, but they know in removing the element hydrogen came out, so they were quite satisfied, by measurements of volume. Their volume measurements were of the same order of magnitude as what they got with the same types of heat treatment.

It has impressed me that in a number of places in this symposium we have talked about number of nuclei which, some years back, would have been regarded as a very high-brow thing for the AMERICAN FOUNDRYMEN'S ASSOCIATION to spend quite a little time of the day's session on. It seems to me that it is something which should bear fruit as time goes on, and I think Mr. McMillan's showing that the nuclear number decreases with time, under a condition where in a very short time he could get enough large-sized nuclei to count, is a decided contribution to our thought on that subject. It has seemed at all times that the nuclear number should decrease with time because the surface energy of the graphite will be less the coarser the graphite, therefore, large lumps of temper carbon should be stable toward smaller.

MR. COWAN: I can't understand just exactly why it should be that a sample that is quenched from 900°F., after having been held many hours, should have more nuclei than one that is slow-cooled. The time element connects up with what Mr. McMillan has said. If it be hydrogen, certainly the hydrogen must be the same in both cases. There must be something that is responsible for the effect.

MR. MCMILLAN: One gentleman in discussing the matter of the tensile strength stated that as the number of nuclei increased the physical properties dropped off. Some years ago we were making tests on what

* Schwartz, H. A., Guiler, G. M., and Barnett, M. K., "*Significance of Hydrogen in the Metallurgy of Cast Iron*," TRANSACTIONS, American Society for Metals, vol. 28, p. 811 (1940).

we called fine-grained iron. We counted the graphite nuclei in the field and then proceeded to qualify it by something and got it down to nuclei per sq. in. on a photomicrograph. That represents about 100 to 150 nuclei in the field. The first one showed a 49,500 yield, 69,500 tensile, 12.5 per cent elongation; the second, 40,800 yield, 58,700 tensile, 18.8 per cent elongation; the third, 41,500 yield, 59,500 tensile, 15.6 per cent elongation. The difference lies in that the first had a heat treatment in which the iron had been preheated and was held at 1700°F., cooled to room temperature in a half hour and held at 1225°F. for three hours. That was the annealing cycle for the one that showed what we call 50 and 70 and 12½. The other ones were preheated and simply went through the short cycle anneal, 15 hour cycle, and it reflects very much the physical properties that this short cycle annealing practice would give, that is, roughly, 44,000 yield, 56,000 to 60,000 tensile and 15 per cent elongation. There is this much evidence at hand here that the fine grain does not have inferior tensile properties.

I believe Mr. Lansing mentioned that perhaps we have been preheating all the time in the tunnel-type kilns and in the periodic ovens. We naturally heat slowly up to 600, 700, 800 or 900°F., and there would be a period in which we would have the effect of preheat. That is true to a certain extent. I might say that normally the low silicon iron will have a count of about 18, as we think of it, and the high silicon iron will count around 50. The preheat treatment will run the count on a high silicon iron up to 150. It will run from three to ten times what the count has been without the pretreatment. That is on high silicon irons. On the low silicon irons with the count of 18, the pretreatment will bring it up to 35 or 45, which is a considerable increase. Now, when the iron is annealed in the long cycle, the 96 hour cycle, it has the 18 count. If you heat the same iron in the so-called direct-fired furnace, such as you do when you walk the temperature right up in the atmosphere type furnace, the count will run around eight or ten, so there is indication that there is some pretreatment when the iron is going through a periodic furnace, which is to be expected. There is this much evidence that low silicon iron with direct firing or direct heating, has a count of around eight or ten, around 18 with a Dressler kiln with a longer cycle, and about 40 when the iron is preheated.

The high silicon iron when run through the short cycle furnace has a count of about 50. When it is run through the Dressler kiln, the count ranges between 25 and 40, so that is not far out of line from the normal count when it is run through the short cycle furnace, but there is not much evidence of preheat treatment there, inasmuch as that same iron should run up to 150 or 200. We have had them as high as 300. In connection with what may take place, we had a heat one day where the silicon got down pretty low, and we proceeded to add a considerable amount of silicon to it. It so happened we had about 20 test bars out of that furnace, for some reason, and we had a good opportunity to play with that iron. We did everything you could think of with it, but it would not respond to pretreatment at all. We couldn't get the count over 18, so possibly that is a matter of oxidation. It may be a matter of

subsequent deoxidation by the addition of silicon to the heat. In other words, we might kill the heat and then destroy whatever nuclei there may be.

I might say that we also made determinations as to the range in which this preheat treatment would do some good. We found very little advantage at 500°F. and very little advantage at 1100°F. At 1100°F. it was not consistent. If we stayed within that range, above 500 and less than 1100°F., the treatment was quite effective.

C. O. BURGESS[5]: Dr. Lorig referred to some work done in our laboratory and our results agree with his very closely. We found that, using temperatures under about 600°F., we had to increase the holding time in order to get the full nucleating effect from these prebaking or preheat treatments. (Incidentally we prefer the term "baking" treatments to differentiate them from the regular anneal.) We also found that with certain irons a discontinuity existed between a temperature of 500 and 1000°F., in the baking treatment. In other words, below 700°F. we might get only moderate refinement of graphite nuclei and above 700°F. we might get very considerable refinement.

From the few tests we have available it also appears that there is probably a critical size of nuclei with which the best properties are developed, for instance, a nucleus size between a very coarse and relatively fine type. There was some improvement in properties on development of a finer type than normally found in an unbaked iron. It is possible, however, that a still greater refinement would have an adverse effect on the properties.

I believe Dr. Schwartz pointed out that on holding some of these irons at a baking temperature of 600°F. under vacuum, we found that some hydrogen was actually given off.

MEMBER: Mr. McMillan made the statement that the number of carbon nuclei decreased on continued heating past first stage anneal. I wonder if the physicals changed as the continued heating passed that point?

MR. MCMILLAN: Unfortunately, this paper covered only the first stage of annealing. The iron samples were removed from the furnace at 1700°F. and we did not make any effort to pull them at all.

MEMBER: When the iron was held for three hours at that first stage and so many nuclei formed with, I suppose, attending graphitization spots, was the same iron held again an added four hours? If so, what becomes of the holes that are originally formed? Is there any indication that the carbon would be dissolved and move, leaving the hole?

MR. MCMILLAN: It was not the same specimen. All the iron that we tested was cast in the same mold. There were two test bars in a mold. We took portions of these bars and heated them in the furnace and just pulled out one portion after three hours, four hours, five hours, six hours, etc., so we didn't actually look at the same specimen. It was the same iron, out of the same mold, so we felt they should be representative. It was not counted at the surface of the bar, the count there being lower

[5] Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

than it is in the center. The bars were electrically heated in a normal heat treating furnace, with no effort being made to control the atmosphere.

MR. JUNGE: I would like to point out the fact that it is quite important when you are doing critical work on nodule count that you always consider the section size of the particular specimen you are studying. In other words, if you have an A.S.T.M. bar, it may make quite a lot of difference whether you take the grip end of the bar near the end where the gate joins on to the grip end, or whether you take the gauge length. In doing comparative work, one should have the same section size because cooling rates make quite a little difference in the nodule number.

MR. MCMILLAN: It is very important that you maintain the same section size, and we took a ¾-in. section of test bar, far enough away from the gate to be unaffected by shrinkage at that point. In a ½-in. section you may get finer counts and different conditions.

MR. MCKINNEY: Referring to Mr. Cowan's paper, our experience differs decidedly from the statement Mr. Cowan makes that in the first stage of the anneal, a carburizing atmosphere should be used. Usually a carburizing atmosphere will greatly retard the first stage of anneal because there must be some start of movement of carbon toward the surface. We had one practical experience in which we had some of our packing material become contaminated with coal and coke, and it was absolutely impossible to anneal in anywhere near the same length of time as it was when the packing was either inert or oxidizing.

MEMBER: In regard to the particular point just mentioned, we took a piece of cupola malleable, silicon 0.67 per cent and carbon 3.10 per cent, and annealed it in the laboratory furnace in an atmosphere of CO. When it was removed, at about 1000°F., it had no skin, and we could tell by the short break that apparently the tensile was extremely low. We put it back in the furnace and held it for 25 hours under the same atmosphere, took it out, and we had about 22 per cent elongation on that piece. The first anneal was carried out in 8 hours from the time it entered the furnace.

MR. MCMILLAN: Was that a constant equilibrium CO or was it a flow?

MEMBER: That was a constant equilibrium CO. There was no flow. The tube was sealed.

CO-CHAIRMAN JOSEPH: In some of our experience on radiant tube malleableizing ovens, we added to one of our ovens a Charmo gas which runs very high in carbon monoxide, around 30 per cent, and the iron malleableized in the same time as the iron going through a radiant tube oven where the carbon monoxide is very much lower. In fact, when we first malleableized iron in our radiant tube ovens, we used DX gas in one oven and the atmosphere at the first part of the furnace ran around 15 per cent carbon monoxide and 3 per cent to 4 per cent carbon dioxide. As the work progressed through the oven the carbon monoxide dropped off to around 12 per cent at the middle of the oven, and, toward the end, the gas became leaner, possibly around 11 per cent CO and around 7 per cent CO_2. In recent years that has been changed, due to the fact that

we have changed to this Charmo gas, which does not give a much higher carbon monoxide content gas in the oven. We have found no change in the annealability of the iron with the rich atmosphere. In fact, with the rich atmosphere in the production of pearlitic malleable we find that, naturally, the carbon nodules come to the surface of the casting. With the lean atmosphere, which runs higher in carbon dioxide, the carbon nodules are in from the surface of the casting, so you naturally do get more decarburization. The atmosphere runs around 12 per cent CO and 7 per cent CO_2 against the higher carbon monoxide atmosphere of possibly 20 per cent to 30 per cent CO and around 1 per cent to 2 per cent CO_2.

MR. MCKINNEY: It is really not the definite content of either one gas or the other that counts, but the balance between the CO and the CO_2. In fact, any atmosphere will anneal perfectly well. It is just the speed at which it is done with one or the other. The important thing is really the balance of CO to CO_2 and not the gas that you put in.

MEMBER: Would Mr. Junge care to elaborate just a little bit on the relation between degree of cooling and kinetics of graphitization.

MR. JUNGE: We know that in thin sections we probably have a higher rate of cool than we do in heavy sections in the white iron, and we probably have a finer structure of carbide and austenite occurring at the freezing temperature. If we have a finer distribution of these two constituents, we have a greater surface area, and we have more opportunity, perhaps, for graphite nuclei to form than we do in the heavier section. As a matter of fact, in thin sections there is a higher nuclei number than in heavy sections, and the explanation that I have is that there is more surface area and, therefore, possibly more austenite-cementite interface.

DR. LORIG: In regard to the same paper, I would like to ask Mr. Junge if he feels that all white iron is supercooled prior to its solidification. If that is so, then the liquid metal in the center of a solidifying mass of white iron must also be undercooled, even though it is in contact with solid iron crystals and the rate of cooling may not be particularly rapid. Any mechanism for explaining the solidification of white iron must also explain how a white iron core can sometimes be found in a section of a casting completely surrounded with a heavy rim of graphitized iron. Sometimes the white iron areas are merely spots. The graphitized iron may have a structure characteristic of gray iron. This raises the question whether there are local areas which may be supercooled in a freezing melt. Can such a situation exist?

MR. JUNGE: I might give my own personal opinion about what happens in inverse chill which is a gray iron condition and may occur in a cooling fin or a rib or maybe just at the surface of a large, heavy casting. It will be found on fracture that the edges of the fin are gray and the center is normal white iron, without even any tendency to form mottled iron. My conception of what occurs there is that we freeze the outside or we freeze the rib as white iron. We freeze it rather rapidly compared with the center. We have conditions set up for easy graphitization compared with the heavy section. Then we reheat it in the solid

state back to a temperature where graphitization in the solid state can actually occur. I believe if we look over some of the work of Dr. R. Schneidewind, University of Michigan, we will find that he feels that these supercooled structures, as he calls them, the eutectiform graphite in dendritic patterns, result from freezing to a white iron, and then graphitizing in the solid state to an aggregate of iron and graphite. Concerning experiments similar to Dr. Schneidewind's, but conducted on a white iron, using a wedge mold such as he used, I have nothing to offer but I think it would be quite interesting and not particularly difficult to follow up and see what happens.

Western Hemisphere Foundry Congress—I

Designing for Foundry Production

BY DR. ERNEST GEIGER*, SAO PAULO, BRAZIL, SOUTH AMERICA.

Abstract

This paper is one of several papers from A.F.A. members of South and Central American countries for presentation at the Western Hemisphere Congress Session sponsored by the Association. Dr. Geiger, in this paper, makes a plea for a better understanding of foundry problems on the parts of engineers and designers of those countries which are now fast developing their industries. He first submits general notes on considerations of designing for economy and quality in castings, reviewing these points in detail, and shows illustrations of examples where these points apply.

1. Many shop difficulties could be overcome and great economies could be made if care was taken in design details. Generally, draftsmen, when laying down a design, are thinking only of the action of the new machine while rarely do they study the possibilities for casting, forging, and machining the detailed parts. This fact results from the lack of experience they have in everyday foundry and machine shop problems in setting parts in machine tools, in preparing complicated molds, in erection, etc.

2. Usually draftsmen and designers have grown up in the drafting departments and not in foundries, workshops, etc. They are highly specialized in making beautiful drawings, in questions about standardization of sheets of tracing paper and in the numbering and classification of drawings, but they do not feel responsible for what happens when the machines of their drawings go in to production, if the production men do not advise them with practical suggestions. While this is, perhaps, not happening in the more advanced industrial countries, unfortunately it is an everyday

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matter with those technicians working in countries where industry is now just developing. Conditions are bad when men are self-centered and jealous, when they will not accept any suggestion because they would then have to descend from their pedestals. Many of these "difficult to get along with" men are scattered in the workshops and in the drafting rooms of our old and suffering world.

3. In our countries, where industry is just now in the development stage, a few men are found who want to follow the practices as used in the more advanced industries of the more advanced countries. These men want to overcome the lack of knowledge of advanced processes and of skilled men; they succeed sometimes, but at what a cost. They want to change over from the primitive casting, forging and machining methods, though the cares of supervision and the lack of time do not permit them to give attention to the details of the work that is needed. They want to make large and complicated machines, but the condition under which they work leads to difficulties, this being perhaps caused by a lack of study of the details.

4. Some of our problems are to cast huge hydraulic press parts and large pneumo-hydraulic accumulators in a small steel foundry, to make castings instead of forgings, and to obtain tolerances of 0.005 in. with old or homemade machines. In order to get initial economy, through using poorly designed parts and poor foundry methods, the steel castings are often quite defective due to blow holes. Those making the castings attempt to remedy their defects occasioned by their poor furnace and molding practices—they will not take suggestions for improvement—by filling holes by welding. In welding the first weld often cracks when a second weld is being made, and so one weld leads to another for a long succession of welds and time. They will, however, continue to make these large high-explosive pneumo-hydraulic accumulators and they will continue to make the huge presses. They do not have adequate sized machines to finish the larger parts but they do this work in small sections, setting them up by hand, and, when possible, rigging up a lathe or grinding machine to cope with this work.

5. Considering the above mentioned "work atmosphere," it seems appropriate to recommend to these men some rules of good machine design, the first referring to casting practices, as generally the foundry work is the first performed in producing a new machine. These rules for the design and production of castings seem

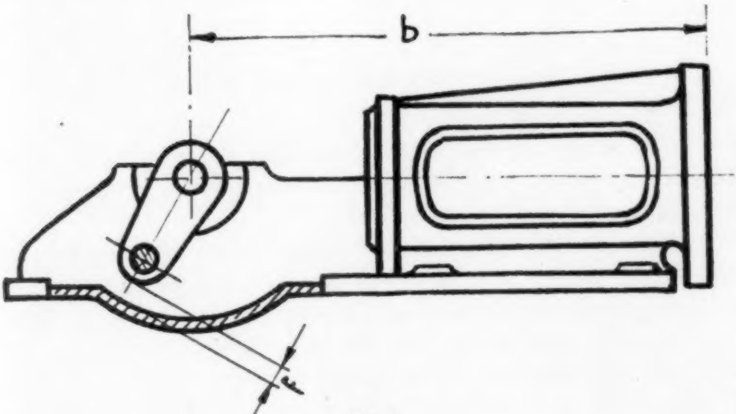

FIG. 1

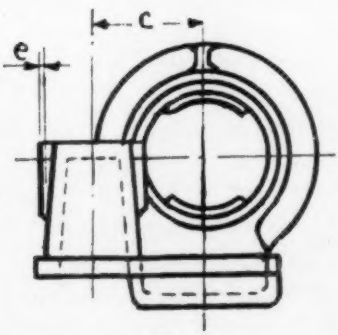

FIG. 2

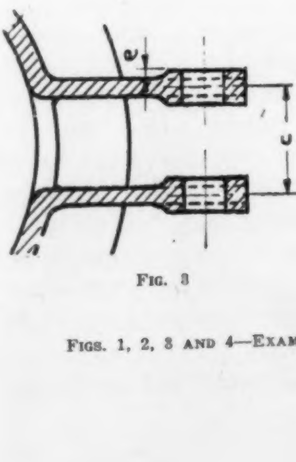

FIG. 3

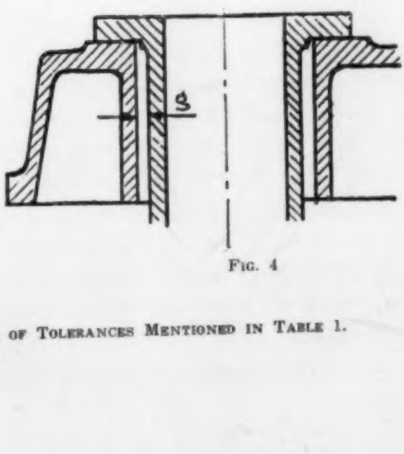

FIG. 4

FIGS. 1, 2, 3 AND 4—EXAMPLES OF TOLERANCES MENTIONED IN TABLE 1.

to be most needed in those plants working along the lines mentioned above.

NOTES ON THE DESIGN OF CASTINGS

6. (A) *General*:

(1) It is always desirable to consider the possible eventual necessity for quantity production of a part, even if at the time of the design only one piece is needed.

(2) Avoid unit construction of large designs or pieces of very complicated design. Consider the difficulty of supporting large and heavy or complicated cores. Remember that not everywhere are available foundries capable of making larger castings successfully and that many are not equipped for large capacity. Perhaps all these and other needed things will not be found in any one foundry. Accordingly it is better to make the design of a large construction as an assembly of several smaller parts which may be machined separately and fitted together later, using shoulders or pins for the alignment and fastening the parts together by bolts, screws or other means.

(3) Avoid protruding parts such as brackets, arms, etc. They should be made from separate patterns which after casting and machining may be secured and aligned to the principal body. This provides an easier and more economical method than if they were cast as one piece with the principal body.

(4) For large circular designs of castings the molds may be made with sweeps, as in loam or sweep molding without the use of expensive flasks, using pits in the foundry floor. Study this possibility when designing such parts.

(5) For the smaller parts avoid designing with panels or walls less than 1/4 in. thick because of the possibility of chilled sections due to fast cooling. For quantity production of small parts, not to be machined, a thickness of 5/32 in. in sections may be used, for even if a certain percentage of pieces is rejected because of chilled sections, the economy obtained by the lighter weight compensates.

(6) Specify on the drawing, the special properties needed in the metal to be cast, such as hardness, soundness, acid resistance, indicating these in such a way that the foundry will exercise special care in selecting the metal to be employed and the process used in molding.

(7) When a circular or cylindrical part which will later be em-

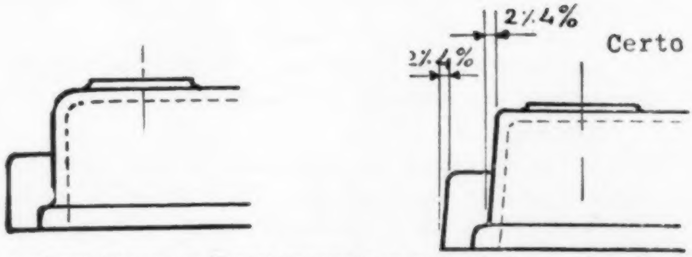

FIG. 5—(LEFT) WRONG AND (RIGHT) CORRECT DRAFT TO PERMIT EASE OF PATTERN'S WITHDRAWAL.

ployed in two or more parts but which will be machined to size as only one piece (example, a bearing), it has to be cast as one piece too, for later on it will be divided or cut apart as necessary for installing, only after first being machined.

7. (B) *Choice of Materials*: Points to consider in choosing metals for parts to cast:

(1) Remember that cast iron cannot be used where elongation or bending are necessary qualifications.

(2) Specify definite minimum requirements for stresses to be met by the metal as these cannot be left up to the judgment of the foundryman who does not know under what conditions the castings he is making are to be used.

(3) When castings have to resist the action of heat or acids, alkalis, sea water, etc. it is best to avoid designs where chaplets must be used to support cores; the design should provide for the support of the cores through core prints.

(4) Avoid use of designs of castings needing chaplet support of cores where the castings will have to withstand high internal pressures.

8. (C) *Shape of Parts*:

(1) Study design of parts to permit for ease of drawing patterns from molds.

(2) Wherever possible design of parts for castings having undercuts or bosses should be avoided.

(3) The pattern should be divided in the simplest manner; avoid the need of many subdivisions.

(4) Ribs, bosses and every protruding part of the pattern should be so designed that, as parts of the pattern, they may be drawn from mold as fixed part of the main pattern, and is so drafted that the pattern does not require loose pieces.

(5) Wherever it is possible, avoid the need of cores.

(6) If cores are unavoidable, design the part:

(a) So that the cores do not require chaplets for supports,

(b) So that the cores can be reinforced by arbors, or rods when needed.

(c) So that it is possible to remove the arbors from the cored hole and for ease in cleaning the cored hole.

(d) To require the least number of cores in any one mold.

(e) So that the cores may be made and drawn on core machines.

9. (D) *Design Considerations for Casting Ease*:

(1) Thicknesses of sections of patterns must be so proportioned as to permit steady flow of the metal, avoiding sections which would interrupt the flow of the metal which would cause cold shuts.

(2) Patterns should if possible permit cores to be vented from the top to permit ease of escape of the gas, and patterns so designed that the castings can be filled from the bottom even though it is necessary to use specially prepared runners to get the metal into the casting at the bottom.

(3) Design the part so that it may be molded with any machined surfaces in the drag side of the mold as the drag side of the casting is the easiest to produce with the least blemishes. The designer can aid in this by designing the part for ease in drawing the pattern with the machined side down.

(4) Avoid designs which necessitate molding large horizontal surfaces.

(5) Avoid metal sections which will cause internal stresses and shrinks. Provide for possible machining of ribs and bosses.

(6) Avoid abrupt changes of thickness and sharp corners.

(7) Consider shrinkage possibilities. Make provision in design so that on cooling no parts of the casting are stressed either by ten-

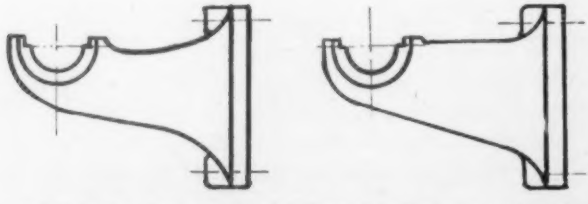

FIG. 6—CURVED SURFACES REQUIRING HAND FINISH OF PATTERNS (LEFT) MORE COSTLY THAN STRAIGHT SURFACES (RIGHT).

sion or compression where free contraction is hindered.

(8) Design for large fillets, especially for parts which have to be heat resistant or fatigue resistant. Sharp corners are liable to cause cracking of the castings in such use.

10. (E) *How to Avoid Shrinks and Internal Stresses*:

(1) If shrinkage is unavoidable, make provision so that the shrinkage will occur in feed heads or runners.

(2) Holes and shrinks appear in:

(a) The heaviest sections.

(b) Ribs, bosses and fillets where they join with the main section.

(c) Where gases cannot escape from the mold surface.

(3) Internal stresses and cracks are most likely to occur when the pattern has uneven sections or abrupt changes of sections causing uneven cooling. To avoid this:

(a) Design for even distribution of metal and thicknesses of section permitting uniform solidification.

(b) Relieve internal stresses by designing pieces as curves.

11. (F) *Casting Cleaning*:

(1) Provide for use of cleaning all casting surfaces, internal and external.

(2) Design parts with openings to permit the withdrawal of core irons and supports and to permit ease in removing the cores.

12. (G) *Tolerances*:

Deformation of wood patterns caused by ramming of molds, imperfections in cores, metal shrinkage, etc., cause castings to have dimensions different from the drawing, so tolerances for sizes of castings should be indicated for those castings having surfaces to be machined (Figs. 1, 2, 3, 4).

13. (H) *Amount of Draft*: (Fig. 5)

Draft of 2° to 4° is needed to permit ease of drawing the pattern from the mold. This is of special importance for quantity production methods using molding machines. Marking of the drawing or blue print with the amount of draft is necessary to permit calculations for space required for screws, etc.

14. (I) *Simpler Shapes*: (Fig. 6)

Curved shapes requiring hand finish of patterns increase the cost of patterns.

15. (J) *Bosses and Protruding Parts to be Machined*: (Figs. 7, 8, 9, 10, 11 and 12)

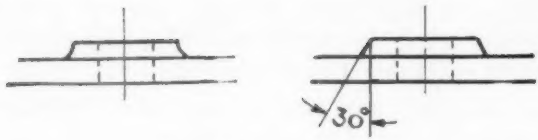

FIG. 7

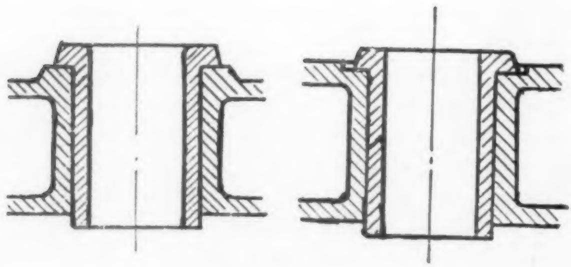

FIG. 8

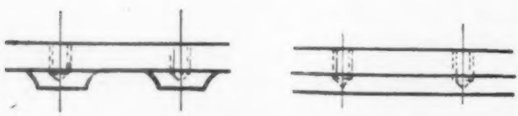

FIG. 9

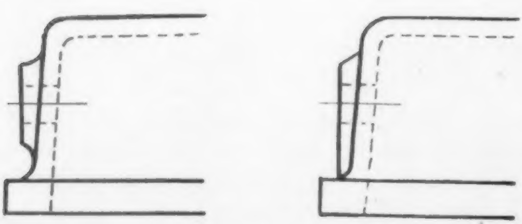

FIG. 10

FIGS. 7, 8, 9 AND 10—WRONG (LEFT) AND CORRECT (RIGHT) DESIGNS FOR BOSSES AND PROTRUDING PARTS.

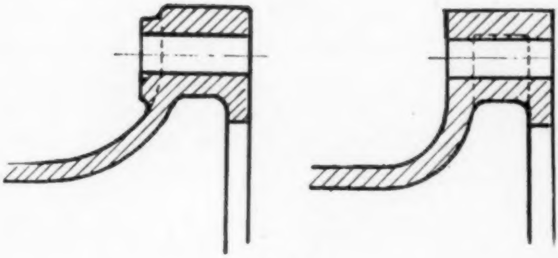

FIG. 11

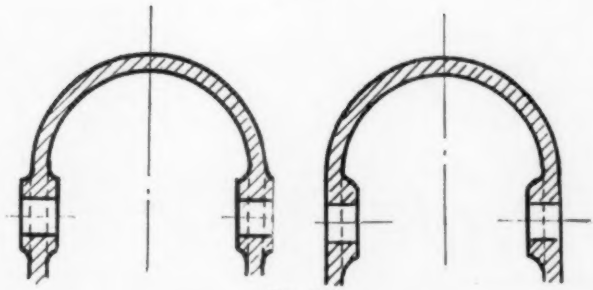

FIG. 12

FIGS. 11 AND 12—WRONG (LEFT) AND CORRECT (RIGHT) DESIGNS FOR BOSSES AND PROTRUDING PARTS.

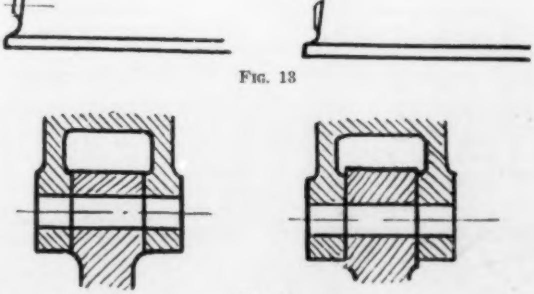

FIG. 13

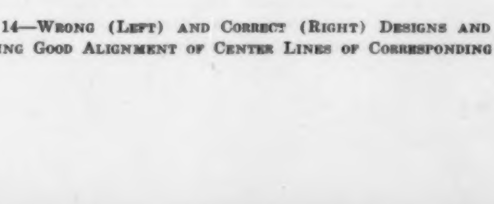

FIG. 14

FIGS. 13 AND 14—WRONG (LEFT) AND CORRECT (RIGHT) DESIGNS AND TOLERANCES FOR GETTING GOOD ALIGNMENT OF CENTER LINES OF CORRESPONDING PARTS.

Table 1

RECOMMENDED TOLERANCES FOR CASTING MEASUREMENTS

Tolerances for	*Castings with Dimensions* up to 20 inches	up to 80 inches	of more than 80 inches
Wall thicknesses (Plus or minus per cent)	+ 6 / — 2	+ 8 / — 3	+ 10 / — 3
Outside dimensions (Plus per cent)	+ 2	+ 1	+ 0.5
Length between center lines—C, Figs. 2, 3 (Minus per cent)	— 1	— 0.5	— 0.2
Minimum thickness of bosses to be machined—(in.)	3/16	9/16	1
Minimum clearance between moving parts, one being machined, the other rough (in.)	3/8	9/16	1
Minimum clearance between two rough parts (in.)	3/8	3/4	1 and 3/8

Contours of bosses should have 30° slope to avoid the use of plastic fillets. Use of bosses should be avoided:

(1) When they can be machined in by counterboring or milling.

(2) When a rib construction can be substituted for a line of

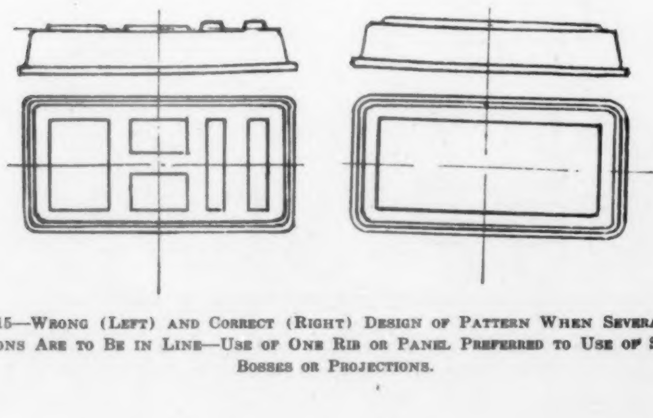

FIG. 15—WRONG (LEFT) AND CORRECT (RIGHT) DESIGN OF PATTERN WHEN SEVERAL PROJECTIONS ARE TO BE IN LINE—USE OF ONE RIB OR PANEL PREFERRED TO USE OF SEVERAL BOSSES OR PROJECTIONS.

FIG. 16—WHEN FLANGES ARE TO BE LEFT UNMACHINED CORRECT WAY (RIGHT) IS TO HAVE ONE FLANGE WIDER THAN THE OTHER.

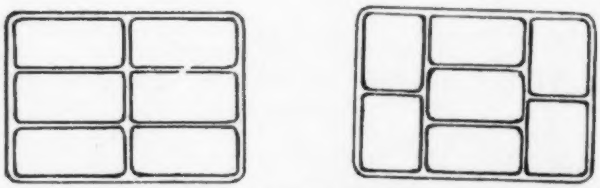

FIG. 17—CORRECT WAY (RIGHT) TO STAGGER RIBS AS COMPARED TO COMMON WAY WHICH IS CONDUCIVE TO SHRINK SPOTS.

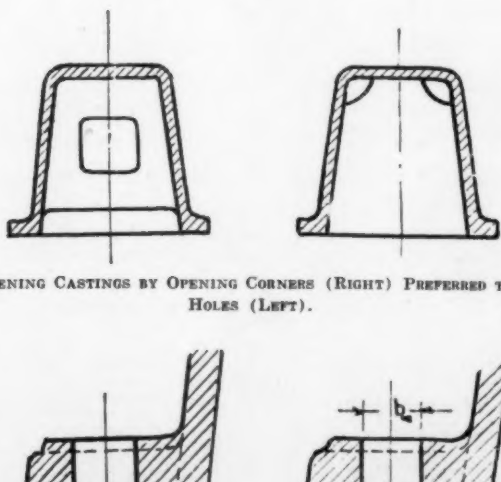

FIG. 18—LIGHTENING CASTINGS BY OPENING CORNERS (RIGHT) PREFERRED TO PANEL CORED HOLES (LEFT).

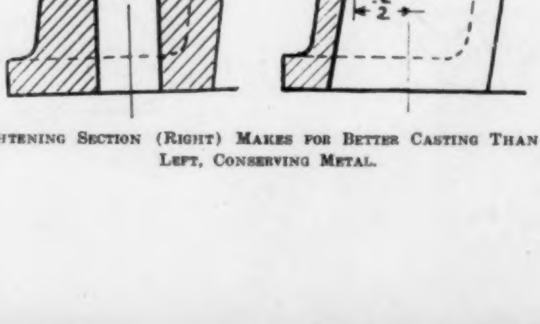

FIG. 19—LIGHTENING SECTION (RIGHT) MAKES FOR BETTER CASTING THAN METHOD ON LEFT, CONSERVING METAL.

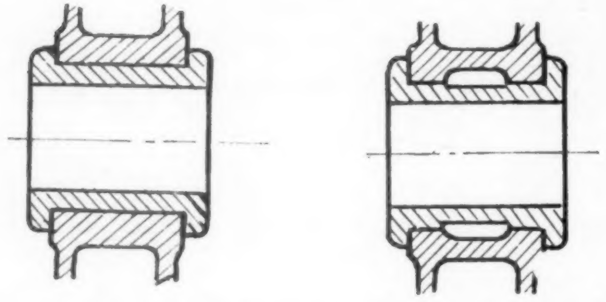

FIG. 20—CORRECT (RIGHT) WAY TO REDUCE METAL SECTION IN PREFERENCE TO LEAVING HEAVIER SECTIONS (LEFT).

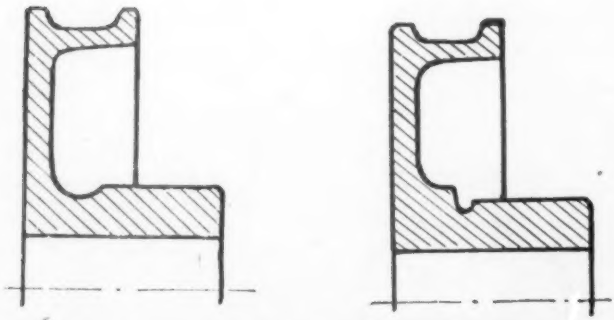

FIG. 21—CORRECT WAY (RIGHT) TO RIG FOR CORE ON UNDERCUTTING PART. THIS WAY WITH RECESSION MACHINED OUT PREFERABLE TO UNDERCUTTING CORE ON LEFT.

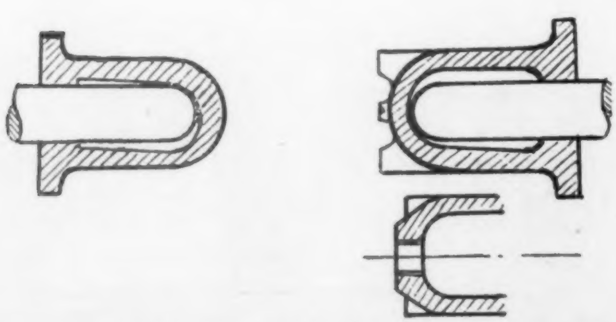

FIG. 22—GREATER SIZE OF CORED HOLE (RIGHT) IN HYDRAULIC RAM CASTING HAS ADVANTAGE OF SMALLER CORE HOLE (LEFT).

bosses difficult to locate and maintain in correct alignment.

(3) When bosses, made as loose pieces on the pattern, are liable to be misplaced or moved when the mold is being rammed up and when they form an undercut. In this case the boss should be projected as part of adjacent flange.

(4) In flanges where the holes are drilled from the inside so that the center of the hole is not likely to center in the boss on the other side. In this and some other cases it is better to substitute for the bosses a rib or to eliminate any boss or rib, thickening the flange and milling in it the locating surfaces for the nuts or the screw heads.

(5) When bosses are on both sides of a panel, where difficulty may be experienced in getting these centered, it is best to make only the outside or the inside bosses.

16. (K) *Locating Surfaces*: (Figs. 13, 14 and 15)

In cases of setting up for machining, and getting the center line of the locating surface of one casting to agree with the center line of the corresponding part, the width of the two locating surfaces should be different (Figs. 13 and 14). The surface pads should be so thick that in the case of a piece warping slightly on cooling, the finishing tool will not cut under the hard skin of the casting. To avoid a new setting of the planing or milling machine for each pad to be surfaced, all the pads should be at the same level (panel of uniform thickness is preferable) as only one reference surface is obtained to speed setting up the part for machining.

17. (L) *Flanges*: (Fig. 16)

When flanges are to be left unmachined, one must be left ¼ to 9/16 in. wider than the other.

18. (M) *Ribs*: (Figs. 17 and 18)

Ribs, as in the cases illustrated, should be staggered to avoid high internal stresses or shrink spots produced during contraction and cooling of the casting. This is preferable to the use of inserting cored holes in the center of rib junctions or centers of the panels for the cores may be difficult to support. Holes in the corners are advantageous for they decrease the quantity of metal to be used.

19. (N) *Lightening Metal Sections*: (Figs. 19, 20 and 21)

Avoid the use of excess metal and cut down machining, yet maintain sufficient strength. Fig. 19, $\frac{g}{2}$, is of the same order as "b,"

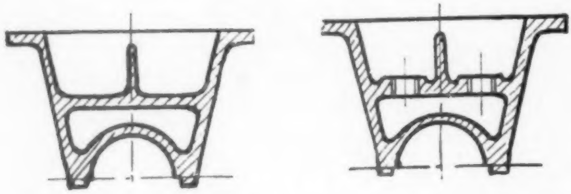

FIG. 23—PROVIDING FOR CORE SUPPORT (RIGHT) WITH EVEN SECTIONS PROMOTING FEEDING OF METAL AS CONTRASTED WITH LESS DESIRABLE DESIGN ON LEFT.

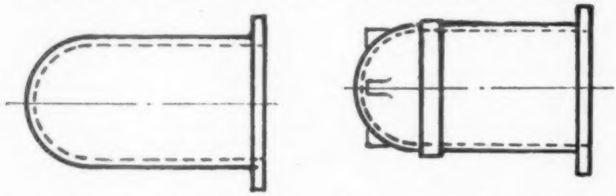

FIG. 24—CORRECT DESIGN (RIGHT) DRAFTED FOR LOCATING EARS AND SUPPORTING COLLARS AS COMPARED TO INCORRECT DESIGN (LEFT).

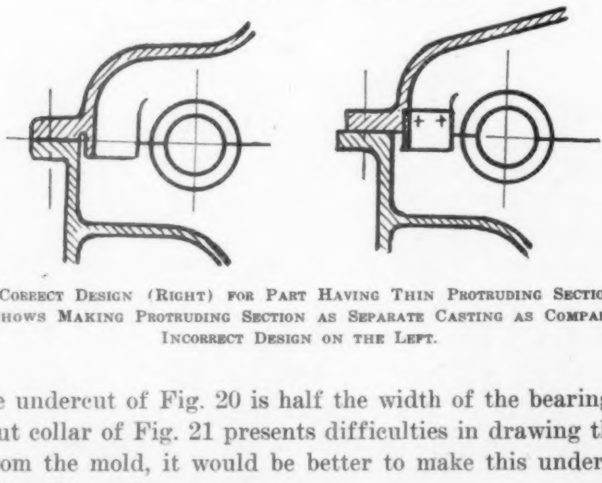

FIG. 25—CORRECT DESIGN (RIGHT) FOR PART HAVING THIN PROTRUDING SECTION. THIS DESIGN SHOWS MAKING PROTRUDING SECTION AS SEPARATE CASTING AS COMPARED WITH INCORRECT DESIGN ON THE LEFT.

and the undercut of Fig. 20 is half the width of the bearing. The undercut collar of Fig. 21 presents difficulties in drawing the pattern from the mold, it would be better to make this undercut by machining the casting.

20. (P) *Cores*: (Figs. 22, 23)

For economy in core boxes, especially when the part is ribbed, care should be taken to have only a few types of cores, standardizing the shapes; also, care must be taken in designing to provide holes to permit access to the interior of the casting for cleaning the inside and to provide core paint support for the cores in the molds. In the case of very long cores, such as for hydraulic pumps, the diameter of the core should be from 1½ to 4 in. larger than the

diameter of the piston (Fig. 22), so it will not be necessary to machine the inside of the cylinder if the core has been slightly off center in molding. When the length of the core is more than twice the diameter, two core support points are necessary and so a second supporting hole is made in the end of the cylinder. The ears

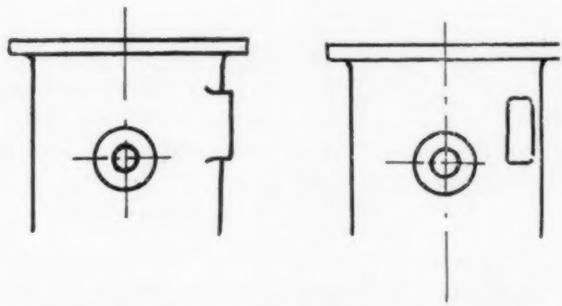

FIG. 26—CORRECT DESIGN (RIGHT) WHEN ADDING PADS AND BOSSES. THIS DESIGN SHOWS BOSSES DRAFTED IN SAME DIRECTION WHICH IS PREFERABLE TO DESIGN SHOWN ON THE LEFT.

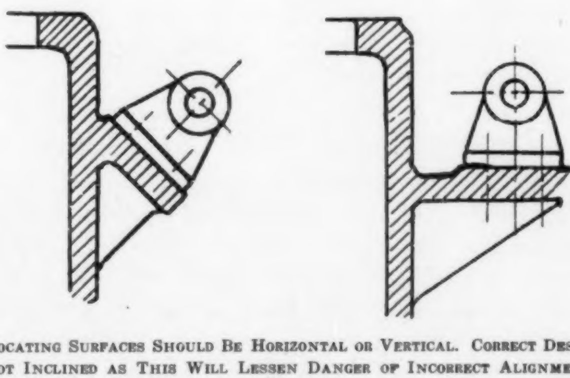

FIG. 27—LOCATING SURFACES SHOULD BE HORIZONTAL OR VERTICAL. CORRECT DESIGN (LEFT) NOT INCLINED AS THIS WILL LESSEN DANGER OF INCORRECT ALIGNMENT.

FIG. 28—PREFERRED PROVISION (RIGHT) FOR CRANE HANDLING OF HEAVY CASTINGS COMPARED WITH LESS DESIRABLE FORM ON THE LEFT.

protruding from the cylinder of Fig. 22 are for location and holding the casting in the lathe.

21. (Q) *Locating Ears and Collars*: (Figs. 23 and 24) The need for locating lugs and supporting collars should be foreseen to provide for the location and holding of the casting in the machining operations.

22. (R) *Protruding Parts*: (Figs. 25, 26, 27 and 28) Very thin protruding parts which can be broken off in shipment add molding difficulties and it is better to make these as separate parts. When many bosses or pads are needed, it is simpler to place them all on one side of the casting so that they may be machined with only one setting of the part in the machine tool.

23. Locating surfaces should be horizontal or vertical and not inclined, for if inclined the correct setting of the piece in the machine will be very difficult as a lateral displacement will mean a vertical displacement also. In this case a reduction in weight is not an economy for ease and accuracy of machining is of more importance. Remember too, provision should be made for holding or lifting a heavy part by a crane (Fig. 28). Protruding hooks are best for this purpose.

CONCLUSION

24. Many more observations and recommendations could be made in this field of designing for better production, many being of direct foundry interest without being needful information to the designer. For instance there is a development of a coiled wire type of support for large cores, one end of which protrudes from the mold to provide for an electrical connection to heat the core support which keeps the metal at that point heated to prevent shrinkage holes; also, there is the use of aluminum powder to raise the temperature of metal to produce better castings but space does not permit the further elaboration of this subject.

25. It is our hope that these remarks may hasten the fuller understanding of the designer of foundry problems, promoting greater cooperation between the engineer and foundryman in these times of emergency.

The Foundry in Mexico

By H. H. Miller*, Torreon, Mexico

Abstract

The author gives a clear picture of the problems and work of the foundrymen of Mexico, covering various Mexican industries and discussing the diversity of production in a Mexican foundry. He tells of the difficulty being encountered now in trying to get parts and metals from outside countries and describes the way in which he and his fellow foundrymen are meeting the situation to keep the industries moving.

1. Now that it is impossible to get new machinery and spare parts from Europe, as well as difficult, and in some cases, impossible, from the United States, it is up to the foundries and machine shops located in Mexico to keep the wheels rolling in all classes of industries. Considering the limited number of large and well equipped shops and the scarcity of many necessary materials, this is an order that taxes our capacities and ingenuity to the utmost, but so far we are doing it.

2. There are no foundry associations in Mexico and practically no attempts at cooperation or exchange of ideas between foundrymen, so one who is busy with his own problems does not have much chance to keep posted on what the rest are doing. For this paper, the writer will have to draw to a large extent on his personal experiences and observations which, however, cover a part of three or four states and, in a general way, will apply to the whole of the country.

Mexican Industries

3. Mexico has a variety of climates, and in topography ranges from tropical jungles to arid table lands and high mountains. Each section has its particular lines of industries, each one with its particular kind of work and problems for the foundry and machine shop. Mines and smelters probably give more work to the foundries and shops than any other single industry. In some sections, there

* Fundicion de Bronce Miller (Miller Brass Foundry).

Note: This paper was presented before the First Western Hemisphere Foundry Congress at the 46th Annual A.F.A. Convention, Cleveland, O., April 20, 1942.

are the oil wells with pumping installations and refineries; cotton spinning mills in others; breweries and distilleries; sugar mills and refineries; cement mills; two or three glass factories; cotton seed oil mills and soap factories; one dynamite factory and the railroads. Then, there are many highly specialized industries, large and small, requiring special machinery not manufactured or used anywhere else that has to be designed and built by the local foundries and shops.

4. There are many diesel engines, large and small, of American and European makes, in use in all parts of Mexico. Even in normal times, a large part of repairs and replacements for these was made in local foundries and machine shops and now practically all of them will have to be made here.

5. The Torreon Foundry and Machine Company of Torreon at present has its machine shop almost full of cylinders, cylinder liners, cylinder heads and pistons for large diesel engines. The patterns were made in their own pattern shop; the castings in their foundry, which is dedicated exclusively to cast iron. They have many tools and special apparatus manufactured in their machine shop for handling this class of work. They also are making a number of retorts for extracting mercury from mercury ore, for there is a considerable amount of mercury in Mexico and with the present large demand and high prices, many with small capital are working mercury deposits that in normal times did not pay. This means quite a lot of work for the iron foundries.

6. This same company has the concession for the manufacture and distribution of the Nordstrom valves for the entire republic, and makes them in all sizes from ½-in. to 10-in., finished and tested in all respects equal to the ones made in the parent factory in California. The patterns, foundry equipment, turret attachments for lathes, special tools, jigs and special machines for finishing the valves were all made in the foundry and machine shop of the Torreon Foundry and Machine Company. As far as is known, no one else makes iron valves in Mexico.

7. There are four factories, two in this state, one in the state of Zacatecas, and one in the state of San Luis Potosi, for extracting rubber from "guayule" (wy-u'-le), a shrub that grows wild on the semi-desert plateaus of this section of Mexico. With the exception of an experimental plant in California, they are the only ones of their kind in the world. Few people of the outside world even know of the existence of this industry and very, very few know

anything about the process used. Three of the factories here and the one in California are owned and operated by the Continental Mexican Rubber Company and represent an investment of several millions of dollars. These companies use a lot of heavy machinery especially designed for the work, and the Torreon Foundry and Machine Company has manufactured practically all that is in use in the Mexican factories as well as the California plant. The heaviest jobs for the foundry are the two and four roll crushers with chilled or steel-jacketed rolls weighing from $1\frac{1}{4}$ to $1\frac{1}{2}$ tons each. The company recently doubled the capacity of its Torreon factory which was a good-sized contract for the foundry and machine shop. Each of the factories also has its own machine shop which is kept busy all of the time on new constructions and repairs. We make some heavy bushings and bearings for the crushers and other machines.

8. The Monterrey Steel Works of Monterrey, and the Consolidated Rolling Mills and Foundries Company of Mexico City make steel rails, iron bars and all kinds of structural steel work. They also have large, well equipped iron and brass foundries and machine shops. The railroads have their own iron and brass foundries and machine shops, while practically all of the smelters, industrial plants and large mines have machine shops, and some of them, their own iron and brass foundries. Most of the iron foundries also make brass, the majority of the brass being melted in tilting oil-fired furnaces, some of the foundries using the crucible furnaces. Very few molding machines are in use in Mexico.

9. In Guadalajara, there is a factory which makes brass valves and plumbers' fittings on a large scale, and the writer believes there are one or two other smaller factories. In Mexico City there is one large valve factory and several smaller ones, and there are a few small ones in Monterrey. The valves made in this country sell for much lower prices than those made in the United States, but many consumers prefer the American-made valves even at higher prices. Stocks of imported valves are now getting low in the hardware and machinery supply houses, and there will be an increase in the sale of the Mexican product.

Diversity of Production

10. With the exception of those making valves, the foundries dedicated exclusively to brass do not specialize in any particular

line but work at anything that is offered. Our company made a bronze cannon for Francisco Madero when he was revolutioning in this part of the country back in 1911 and has made over 50 church bells. Once we had a run on ornamental brass lamps for city streets, and parks, facades for theaters, etc. During one city administration, we made bronze plates for a number of public buildings and some bridges. A few years ago, our company put a ton and a half of brass in a communion rail and a thousand pounds in a base for a pulpit for one of the churches in Torreon. Later, we took a contract to face two small altars in the same church with cast and sheet brass. That took another ton and a half of castings. We started on the job after the war in Europe had been going on for some time and stocks of sheet brass were low. We could not get any from the United States, or at least not without long delays, so the priest in charge of the church and the writer combed Mexico to get enough to finish the work. These are exceptional jobs, however, and just serve to divert our minds from the ordinary run of troubles which beset the poor foundryman in this country.

REGULAR WORK

11. Our regular line of work is bars, bushings, engine brasses, journal bearings and all kinds of castings for repairs, as well as new installations for mines, smelters and industrial plants located in this and two or three adjoining states, with an occasional order from more distant parts. Our company makes bronze bars for airplane valve guides that go to Merida, Yucatan. They are shipped from here to Mexico City by express and from there to Merida by their own airplanes. We make the same class of castings for the air lines working out of Torreon.

12. The Electric Bond and Share Company owns a large part of the light and power plants in Mexico. One of the executives has invented a device which he calls an "adapter" and which is put on the light meters to make it more difficult to use devices for bypassing the meters so they will not register. They are installed on practically all of the company's light meters in the country, and they have an 11/64th-in. screw with 32 threads to the inch and a special head. We tried to get them made in the United States, but the screw manufacturers were not interested. We solved this problem by buying a bench lathe for a mechanic who has a little shop hidden away in a back room of his house where he and his boys do all the

work and do not pay any taxes. There are no salaries or double-time for overtime there, and they make the screws at what, in the States, would be considered a ridiculously low price. There are hundreds of these small shops scattered around the small towns and cities. Many of the owners are expert mechanics and do jobs you would hardly expect to have done anywhere outside of the regular factories where special tools and equipment are available. In our foundry, we make the adapters in lots of one or two thousand, using an aluminum match plate and snap flask to cast them in green sand.

13. The Laguna district, of which Torreon is the commercial center, is primarily an agricultural country, and modern, up-to-date machinery is used on most of the farms. Practically all of this machinery has been imported from the United States and Europe. Now stocks of spare parts are getting low with no hope of getting factory-made parts for the European machines and not much more for those of American make, so they are being made in local foundries and machine shops. Many of the small parts regularly made of malleable iron, cast iron or steel are now being replaced with castings made of brass. Sometimes we use the cold castings for patterns, using wood patterns for some and aluminum patterns for others. We make them in lots of fifties and hundreds, molding them by hand in green sand, or, if there are likely to be repeat orders, we make match plates of aluminum and use snap flasks. These same pieces are made by the thousands, perhaps hundreds of thousands, on molding machines in the factories.

14. The crops of the Laguna district depend entirely on irrigation from the Nazas River, supplemented by water from wells. There are hundreds of drilled wells using large capacity centrifugal pumps and deep turbine pumps. There is a never-ending strean of orders for repairs and replacements for them coming into the foundries and machine shops. There is also continual drilling of new wells which requires either new or reconstructed pumping installations. There are several sections of Mexico which depend on irrigation either from rivers or wells, so the foundries and machine shops in each section have to take care of their installations the same as we do here.

15. Pumps of all kinds are used by mines, smelters and industrial plants in all parts of the republic, so pump runners, bushings and other parts, even to the bodies of the pumps themselves, have always given a lot of work to the foundries and machine shops.

Now, perhaps all of them will have to be made here. The major part of these pieces made in the Mexican foundries are cast of brass, although the originals from the factories are of iron. We have to make patterns for all of the pieces, taking the old castings for models. It requires a skilled patternmaker to make patterns for runners, some of which are of intricate design. Comparatively few of the Mexican patternmakers can make them as they really should be made, and patterns made by jack-leg carpenters posing as patternmakers give us an endless amount of trouble.

16. Not long ago, a molder and helper in our shop spent a whole day trying to make a mold from a pattern sent in by a client and then had to throw it away and have our own patternmaker make a new one. The client who is an agent for a line of pumps goes to the United States and spends a few days in the factory each year. He tells us that in the factory girls make several of the molds in an hour on a molding machine. Now he cannot get the runners from the factory, and we have to make them for him. Our castings will not come out of the sand as smooth as the ones from the factory and will take more work to finish, especially as the machine shops do not have the proper equipment, but once finished and in the well, they will give the same service as the imported ones.

17. In the foundry, we make the cores and molds by hand, baking the cores, of course, and sometimes using iron flasks and drying the molds in the core oven.

18. A large part of the brass castings in Mexico is made from scrap and, in some cases, of just whatever scrap is at hand, regardless of quality. The consumers as a rule are not so exacting as they are in the United States, and it is surprising to see what the foundries and machine shops use at times. Some years ago, the owner of a small shop bought some of the poorest quality brass bars we had in stock. We found out later that he used them for valve guides and bushings in an airplane motor. So far as we know, the plane was never wrecked on account of the bearings.

METAL SITUATION

19. To get back to the question of scrap: At the beginning of the war in Europe, large quantities of scrap iron, steel and brass were shipped there and, also, to Japan. All parts of the country have been combed for all kinds of scrap and speculators have bought up and are holding considerable amounts of brass and

copper for higher prices, with the result that now foundries all over the republic are pretty well up against it for prime materials. Zinc is mined and refined in Mexico, so we presume that we will always be able to get what we need, but the price is going up all the time. Formerly we used English tin when we wanted to make really good bronze castings or church bells. Now that is entirely out of the question, and we have to depend on native tin.

20. There is quite a lot of placer tin in Mexico, as well as some tin mines, but for some reason or other, they do not seem to be worked as extensively as they ought to be. As near as the writer can find out, most of the tin we get is from the placers. The peons pan it out in about the same way as the "forty-niners" panned gold, or, after heavy rains, they just pick up the nuggets in the beds of the streams. Many of them smelt, or rather sweat it out in the hills or in their houses over charcoal braziers, letting it run down on the ground where it spreads out into irregular shapes, and they sell it in that form without even running it into bars. Formerly, we could buy this tin at a low price but it contains considerable impurities, so, while we could get English tin at a reasonable price, many of us used the English tin. There are a few tin refineries in Mexico that smelt the stream tin nuggets and some tin from the mines, guaranteeing their product to be 98, 99 and 99½ per cent pure, according to their brands.

21. One of our customers, a large mining company, bought up several tons of this "stream" tin some years ago and has been sending us what we need to take care of their orders. It runs about 95 per cent pure. Just a short time ago they advised the writer that their stock was getting low.

CONCLUSION

22. As mentioned in the beginning of this paper, the writer's personal experiences and observations will apply, in a general way, to the rest of the foundrymen in Mexico and will give an idea as to what we are doing in trying to keep the industries moving, doing our part in helping to win the war and to "keep 'em flying."

Comments on the Brazilian Foundry Industry

By H. A. Hunnicutt*, Sao Paulo, Brazil, and New York City, N. Y.

Abstract

In this paper the author gives a general survey of the foundry industry in Brazil and describes some of the changes being brought about in it by the stoppage of imports of foreign machinery and steel products. He compares Brazilian cast iron and pig iron to those of the United States and tells what some of the more progressive foundrymen are doing in the field of sand control, cupola operation, metallography, etc. Two technical research institutions are now supplying the industry with information and test results, filling a great need for technical and other data.

Introduction

1. It is not possible to give here a complete and detailed report on the Brazilian foundry industry, although such a study would be definitely valuable toward the promotion of understanding and good will between the foundry interests of these two largest countries in the Western Hemisphere. Conditions and state of development of the industry in these two countries are so widely separated that no effort will be made to compare them point for point. Furthermore, the foundry field in any country has so many factors and phases influencing it that nothing but a very brief and general discussion of the Brazilian foundry industry can be attempted here.

2. Anyone concerned with obtaining information about many industries in Brazil, including the foundry industry, finds it a very difficult problem in that there is a lack of available statistical data. Practically the only solution is for one to go out and get it himself, a rather laborious, expensive and time-consuming procedure. This deficiency can no doubt be traced to the fact that there are no trade or technical associations similar to the American Foundry-

* Industrias Chimicas Brasileiras "Duperial," S.A. Sao Paulo, Brazil, and The International Nickel Co., Inc., New York City, N. Y.

Note: This paper was presented before the First Western Hemisphere Foundry Congress, 46th Annual A.F.A. Convention, Cleveland, Ohio, April 20, 1942.

men's Association, nor trade papers, devoted to supplying the foundry industry with technical and other data.

3. The only way in which the personnel of the industry is linked together is through the "sindicato," or brotherhood, established by the Brazilian government in pursuance of its social policies. This organization furnishes its members with accident compensation, hospitalization and retirement pay, as well as legal assistance in maintaining its members' rights as guaranteed by other federal labor laws relating to working hours, vacations with pay, lay-off protection, etc. These privileges are financed from a fund derived from contributions of 6 per cent of the member's salary, divided equally between employer and employee. The "sindicato" does not concern itself with giving technical service to the members.

4. It is very gratifying to note that the American public is now better informed about Brazil than they were several years ago. In spite of the preoccupation with the national emergency that confronts us, it, no doubt, has been learned that Brazil is larger than the United States in area, has one-third the population, and that the language spoken is Portuguese. Brazil has 20 states which can usually be divided into three groups: northern, central, and southern. In all three, the population densities are largest along the coast and that is where you will find most of the foundries. There are probably not more than 400 gray iron, non-ferrous, steel and malleable iron foundries in all Brazil. Geographically these can be roughly distributed as follows: 15 per cent in the northern zone, 60 per cent in the central zone and 25 per cent in the southern zone.

LOCATION OF INDUSTRIAL CENTERS

5. Population and industry in the northern zone are concentrated along the eastern seaboard, familiarly known as the "hump" of Brazil. Most of the foundries located here are units of the maintenance and repair shops of the large sugar plantations and textile mills, which form a very important factor in this area's economical structure.

6. Travelling south along the coast to the central zone, we find that its hub is at Rio de Janeiro, capital of Brazil. Although the city's most important function is to administer the government of Brazil, there are many important industrial concerns located there, some of them branch factories of American firms. Rio de Janeiro is considered a tourist's paradise by Brazilians as well as foreigners; so many owners of small factories and farms in the outlying states

go there to combine pleasure and business. This gives rise to a small machine manufacturing industry, which, of course, depends on foundries for its cast shapes. Consequently, there are a number of independent foundry jobbers, but, in general, they are attached to machine shops. It is difficult to say which started first—machine shops needing castings, or foundries which started their own machine shops. Probably the best designed commercial foundry in all Brazil is that operated by the Rio de Janeiro Tramway Light and Power Company, Ltd., as one unit of their $5,000,000 repair shop built from scratch about 15 years ago. The other large foundries in the city are almost all of long standing and produce from 100 to 250 tons a month each, in sanitary castings, stoves, and machine parts.

7. Northeast of Rio is a sugar growing center, with its large self-contained factories and plantations. These naturally have their repair shops and foundries, which may be called upon suddenly to repair anything from a broken bolt to a several ton casting. Big repairs are made during the shutdown period and there is at least one foundry in that section that can handle any size or type of cast iron casting required by the sugar factories.

8. North and northwest of Rio is the great mining state of Minas Geraes, with about 20 blast furnaces, several large gold mines, notable among them being the air-conditioned St. John del Rey mine, employing some 8,000 men, and several ore (manganese) extraction and exportation centers. These large firms all have their repair foundries, but it was surprising to the author to find so few jobbing foundries in that area, which centers around Belo Horizonte, the capital of the state of Minas Geraes.

9. West of Rio can be found what is by far the most important agricultural and industrial section of the central zone, and indeed, of all Brazil, namely, the state of Sao Paulo and its capital city of 1,300,000 population, with the same name. Sao Paulo is chiefly known here as the source of the coffee shipped through the port of Santos, but the city of Sao Paulo itself is the largest industrial center outside of the United States. Here can be found more than 100 gray iron foundries, some 50 non-ferrous foundries and an ever-increasing number of steel foundries, now numbering some half dozen (not including a few rolling mills which produce their own steel). These supply the basic castings for a large machine and machine tool industry which, owing to the lack of importation facilities occasioned by the war, is being forced to expand at a very

fast rate. The largest of these firms employs competent engineering staffs, some of whom may be engaged in duplicating imported machinery. They have the ability to recognize important design features and realize the need to employ a high quality material. They accordingly specify them from the foundries. However, there are a great number of small machine shops, owned and operated by skilled machinists, which begin the manufacture of machines and even machine tools by the simple procedure of copying an existing machine, without any idea of the relation of strength of materials to design. These customers place a heavy burden on the foundryman by rejecting castings with excuses, such as, material too porous —not strong enough—too many blowholes—too soft—too hard, etc., when they themselves are in many cases responsible, due to poor design or specification for the material needed in the casting.

10. Passing on briefly to the southern zone of Brazil, which consists of the states of Parana, Santa Catarina and Rio Grande do Sul, we find that agriculture and cattle raising are the most important factors in the economical setup, together with a budding manufacturing industry. Here are located at least one electric steel foundry, a malleable iron foundry, a very important manufacturer of sawmill and wood-working machinery, and a large hardware manufacturer known throughout Brazil. Rio Grande do Sul (home of Getulio Vargas, President of Brazil) is one of the three most important states of Brazil.

Cast Iron

11. The fact that Brazilian cast iron lacks uniformity is the one thing that can be said about it generally. We have already mentioned that the consumer cannot usually supply the foundry with correct specifications for his castings. However, the expansion of the machine manufacturing industry has required many firms, and financially permitted others, to hire men with sufficient training and ability to undertake rational and technical studies of the problems presenting themselves, even if they are not experts in that particular field.

12. On the other hand, there are very few foundries in Brazil that can meet specifications, as they are known here in the states, with any degree of consistency. There are many reasons for this fact.

13. The Brazilian foundryman can hold his own against the

world, as far as the actual art of molding is concerned. His knowledge of sand, metal, refractories, control, and foundry procedure, however, is usually limited to the traditional arts of the foundry trade, and he is, generally, sadly unaware of modern trends and practices as regards cupola operation, coke heights, blast volumes, sizes of charges, sand control, etc. The increasing demands by his customers for better grades of iron have made him realize his shortcomings and the more progressive are making every effort to produce better quality irons. This general lack of knowledge about best modern procedure can be traced, we believe, to the nonexistence of a trade or technical association, as already mentioned before, devoted to serving the industry and keeping it up to date. The Brazilian government, both federal and state, is increasing the number of trade schools constantly, and as many of these have modern foundry apprenticeship courses, the newcomers to the industry are getting a very good start.

14. Another important factor in this question is the foundryman's lack of information upon the constituents of cast iron, and the effect produced by even small variations in their percentages, and methods of controlling them. Many pig iron producers attempt to work to standard chemical compositions of pig iron. On some cases, variations in the composition of the pig in a carload have been found to be so divergent as to render the analyses given almost useless. On the other hand, very few foundrymen calculate charges in order to give a balanced iron in the cupola, so that analyses are generally used to classify the pig as regards their silicon content only, inasmuch as all foundries are naturally aware of the effects of this element. When a foundry gets some castings rejected due to "poor quality" he usually passes the problem on to the pig producer, giving rise to constant friction between the two parties. Very few foundries have chemical laboratories attached to their organization, or within their financial reach, so that a good control of the iron produced is very difficult.

PIG IRON

15. On the other hand, the blast furnaces themselves have a difficult time maintaining uniformity in Brazilian pig iron. We have already said that there are up to 20 furnaces. The largest producer is the Cia. Siderurgica Belgo-Mineira, which is exceedingly well equipped and produces about 100 to 150 tons per day.

Much of this goes to the manufacture of steel in their own mills and the rest goes to the foundry industry, both in Brazil and Argentina. Blast furnaces range down in size from the 60 ton per day furnace of the Belgo Mineira, to a 13 ton per day furnace located in Belo Horizonte. An important factor in limiting the size of these furnaces to such comparatively small capacities is that wood charcoal, with its inherently low compressive strength, must be used due to the lack of native coal near by.

16. The batches produced are therefore small and, together with variations in the ore used, combine to force the producer to send to the foundry carloads of pig iron from many heats, which, although they may have been separately analyzed, are not classified finely enough to maintain uniformity throughout the carload. In general, the characteristics of Brazilian pig are: Relatively low carbon, 3.20 to 3.60 per cent; low manganese, 0.20 to 0.30 per cent; very low sulphur, 0.01 to 0.05 per cent; phosphorus, from 0.20 to 0.30 per cent; and silicon, ranging from 1.00 to 4.50 per cent.

17. Inasmuch as the actual details of Brazilian foundry practice will be discussed by a practical Brazilian foundryman in another paper to be presented at this conference, no attempt will be made to treat this phase of the foundry industry here.

FOUNDRY PRODUCTION

18. Reviewing briefly the Brazilian foundries' products, we find that the industry occupies itself with all types of castings. Possibly the greatest output is in sanitary ware such as bathtubs, wash basins, flushing boxes, etc. The largest tonnages produced by those foundries connected with railroad shops are, naturally, brake shoes, but most are capable of, and do cast the most intricate cylinder castings. Several of the largest foundries are occupied with casting parts for agricultural machinery and agricultural produce processing machinery, such as, cotton gins, presses, coffee and rice classifiers, etc. One foundry specializes in making coffee grinders for individual use, another with automotive and diesel castings, although to keep running they have to accept miscellaneous outside work. Another large foundry in Sao Paulo manufactures pumps and pump parts. Still another makes centrifugally cast iron pipes. One foundry tries not to accept any casting weighing less than one ton, except when needed by their own machine and boiler shop, and can handle anything up to 15 tons. Another de-

rives a good part of its steady income from casting sulphur retorts, used in making carbon bisulfide.

19. A typical problem which is confronting the foundries in Sao Paulo came as a direct result of the war. Complete stoppage of structural steel imports has given rise to a large number of small rolling mills, specializing principally in rounds for concrete reinforcement bars. These naturally need a large number of rolls and are willing to pay fancy prices to foundries which can make good ones. These same fancy prices tempt all foundries to make rolls, with the result that interest in roll making is at a high pitch.

20. Another big item in the Sao Paulo foundries is lathe beds. Practically every foundry the author visited recently was busy supplying lathe beds of all sizes, as well as other castings needed to manufacture this basic machine tool.

21. The steel foundries almost without exception use electric furnaces, the three ton direct-arc type being the most popular. They are usually an outgrowth of the cast iron foundries, so occupy the same plant and installations. The production of steel requires a chemical laboratory which is put to use to the benefit of the cast iron as well. Two or three of the steel foundries have such laboratories. The remaining ones, as well as several iron foundries, are beginning to recognize the necessity of modern up-to-date sand mixing, testing and treating equipment, in order to overcome sand problems for their steel castings. Types of castings produced are varied, being principally railroad castings, forging press cylinders, blanks for forging, etc. Most foundries make use of their spare time by casting ingots for the several rolling mills. One foundry has gone extensively and successfully into the manufacture of special alloys and tool steels for drills, taps and other similar tools. They cast the ingots and forge, rather than roll, the round, hex, or whatever shape and size rod is necessary. They are also equipped to do heat treating, but leave the actual tool manufacturing to other firms.

TECHNICAL INSTITUTIONS

22. There are at least two institutions in Brazil which are endeavoring to promote the technical aspect of the foundry industry. One is the National Technological Laboratory in Rio de Janeiro, which is doing commendable work in supplying those foundries which request them with chemical analyses and microphotographs of cast materials.

23. By far the most stimulating influence is that being exerted by the Institute of Technological Research, a semi-autonomous Bureau of Standards for the State of Sao Paulo. This Institute is extremely well equipped to make thorough investigations as regards testing of materials, concrete analyses, metallography, chemical analyses, ceramics, etc. A new department is the foundry department, and a still newer one is the aviation department. The foundry is modest-sized, but the most modern and completely equipped foundry in Brazil. Briefly, they have a sand control laboratory and mixing equipment, American-made cupola and indirect-arc electric furnaces, a direct-arc 1½ ton furnace, electric core ovens and heat treating furnaces, sand blasting rooms and a very competent staff. Their chemical analyses are supplied by the main chemical laboratory of the Institute.

24. Under Dr. Miguel Siegel's competent guidance, this foundry supplies foundry service to the industry at a modest fee, and has been very successful in solving many problems which involved sand control and cupola operation. They are at present occupied in producing alloy cast irons and steels, and are fulfilling a definite need in that they can supply any specified iron in up to 1000 lb. castings.

Conclusion

25. The Brazilian foundry industry can be said to be coming into its own now and can look forward with great hope for the future. Practically all of the foundries have all the work they can handle, and many are in a position to choose their orders. Many bright and progressive foundrymen are getting their chance to start up in business, new foundries are appearing every month, and old foundries are improving. They are attacking the problems they meet, and are trying their best to overcome the handicaps which they themselves recognize, so that the entire industry can look forward toward an ever increasing efficiency and progressiveness.

A Multipurpose Brazilian Foundry

By L. D. Villares*, Sao Paulo, Brazil

Abstract

The author describes the growth and expansion of a South American firm from one wholly engaged in the manufacture of passenger and freight elevators to one producing high quality alloy cast iron and cast steel, steel forgings and tool steel bars for their own as well as outside consumption. He gives a detailed account of the processes involved, the research problems with which they have been confronted and how, in certain instances, they have made use of 100 per cent Brazilian raw materials.

1. The firm Pirie, Villares & Cia., Ltda. has been manufacturing electric passenger and freight elevators for the last 22 years. With the modern skyscraper trend, which Brazil has followed, the demands on vertical transportation in the new buildings have increased so much that new designs in elevator machines had to be introduced, calling for the application of modern metallurgy. That was the start of our foundry activities.

2. In 1926 we started casting bronze for our own gears and bearings. After much research conducted at the local laboratory of our Instituto de Pesquisas Technologicas, we adopted a low leaded bronze for gears and bearings which has very good wearing characteristics. We investigated well the distribution of the lead in the bronze in different castings and found that this distribution was very uniform (see Fig. 1). The lead has anti-friction properties which make it especially suitable in a worm gear where friction is very high. After 16 years of field observation we can confirm the good qualities of this leaded bronze for this application.

3. Our next problem was cast iron. We needed better cast iron for our elevator parts than the local foundries could supply. Undoubtedly this problem could be solved by an ordinary cupola furnace, but as we had in mind the production of steel later on, we decided to install an electric furnace of the direct-arc type which could be used both for high class cast iron and for steel. At present our equipment is composed of (see Fig. 2):

* Pirie, Villares & Cia., Ltda.

Note: This paper was presented before the First Western Hemisphere Foundry Congress, 46th Annual A.F.A. Convention, Cleveland, Ohio, April 20, 1942.

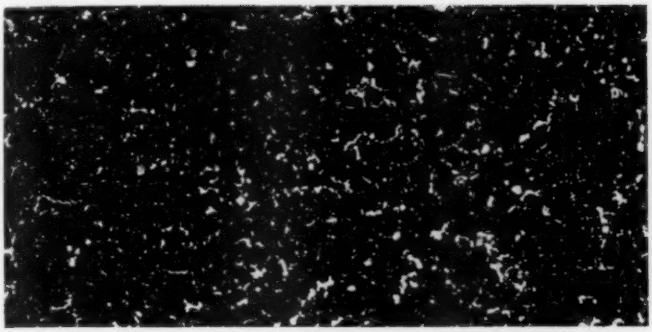

FIG. 1—LEAD DISTRIBUTION IN A LEADED BRONZE CASTING. x20.

One 3-ton direct-arc type electric furnace
Three cupola furnaces (two of 15-in. and one of 24-in.)
One muller type mixer
Three mold and core ovens
Four molding machines
Sand blast cleaning equipment with rotating table cleaner and hand jet with air filters
Two 5-ton traveling cranes
One chemical laboratory with a four-minute carbon determinator and other apparatus.

CAST IRON

4. We started casting high-strength iron with the electric furnace, charging steel shavings and scrap to a great extent. According to the product desired we charge more or less steel shavings and with this method we can obtain a cast iron of desired analysis. While still in the furnace, we take out a sample of metal which, after breaking and observation of the grain structure and white tip, is analyzed for carbon, eventually corrected and poured. With this method, we have obtained very good results on plain and alloyed castings.

5. One important casting for our elevators is the cable sheave which must have a close-grained iron of the high-strength type. We easily attained this result with our standard 25 grade (see Fig. 3), (25 meaning the approximate breaking stress in kilograms per sq. mm.). This type has a very regular hardness and grain structure all over the cross section even in large castings (see Fig. 4). Usually we use a Brinell hardness of 200 to 220. Traction sheaves have shown very good wearing qualities with this cast iron. In some

special cases, we have gone as high as 240 Brinell. Special precautions are taken in the molding procedure, owing to the greater shrinkage of such high breaking stress types of cast iron.

6. Recently, we have been casting chilled rolls for cold rolling of steel strips from our electric furnace, with and without alloys. Foundry sand studies have been made continuously for the last 3 years and, with the help of our Instituto de Pesquisas Technologicas, we have made great improvements. Although we originally intended to cast only for our own needs, we are at present producing more castings for outside clients than for our own elevator factory.

7. The local machine and machine tool manufacturers have found that, for their shell turning lathes, plate shears, large hydraulic presses, etc., it is not only more economical but also valuable to their business to pay more and have the good castings with accurate specifications which we are able to make with the electric furnace and our technique.

8. We have done considerable work to introduce good quality castings in this market and we offer three standard qualities of iron which meet most applications (see Fig. 3). Considerable work has been done to induce our own engineering department and the local machine manufacturers to redesign their castings, taking into consideration the high breaking stress cast iron produced in our foundry.

FIG. 2—VIEW OF MAIN BAY OF FOUNDRY.

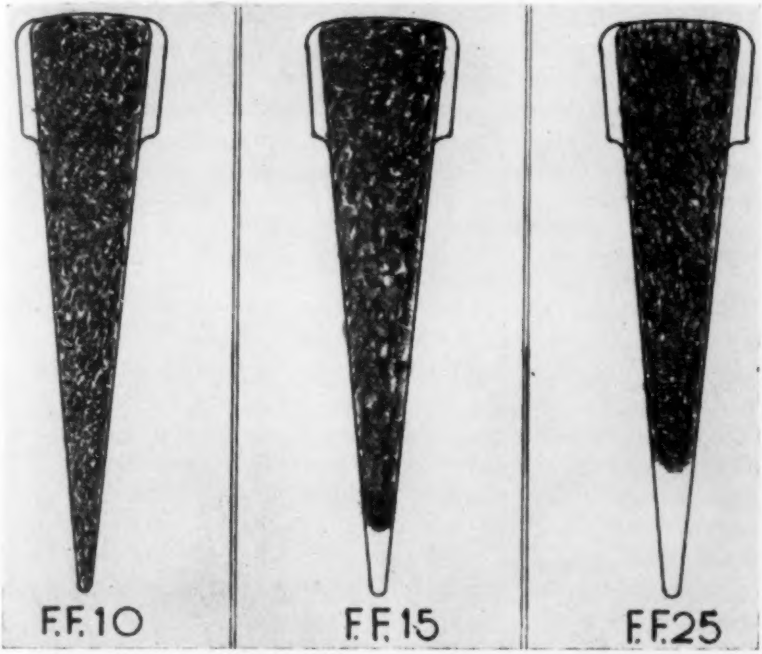

FIG. 3—STANDARDS FOR CHILL TESTS.

Type of Iron	*Casting Section, Thickness mm.*	*Range, in.*	*Analysis, Per Cent: Carbon*	*Silicon*	*Manganese*	*Application*
10	4 to 10	$\frac{5}{32}$ to $\frac{13}{32}$	3.3 to 3.5	2.0 to 2.5	0.6 to 0.8	*Thin Sections Easily Machined*
15	10 to 20	$\frac{13}{32}$ to $\frac{25}{32}$	3.0 to 3.2	1.8 to 2.0	1.6 to 1.8	*Medium Sections Medium Strength*
25	Above 20	Above $\frac{25}{32}$	2.9 to 3.1	1.6 to 1.8	0.6 to 0.8	*Large Castings High Strength*

The Illustration Shows the Appearance of Chills for Tests for the Corresponding Grades.

9. Over Saturdays and Sundays, we run our electric furnace on synthetic pig iron for the production of white pig iron for the local malleable foundries that imported this material from Sweden or for special pig irons for remelting purposes, manganese content ranging from 0.2 to 2 per cent or more and silicon from 0.3 to 3 per cent and more, with very low phosphorus and sulphur.

CAST STEEL

10. Last year, we started taking into consideration steel casting, again first for our own needs. After sand studies carried out with the help of the Instituto de Pesquisas Technologicas, we succeeded in using 100 per cent Brazilian molding materials. After

some research, we found a binding clay which gives very good results. Today, we cast steel in sizes varying from a few kilograms up to 3 tons, such as large sugar mill gears, hydraulic press parts (up to 1500 tons), rolling mill cages, pinions, etc., either in plain carbon steel or alloyed with nickel, chromium, vanadium, etc. All steel castings are annealed or otherwise heat treated in oil-fired furnaces.

TOOL STEEL

11. With the shortage of this material in our country, we started to cast ingots with very interesting results. Today we are producing steel in bars varying from about 1½ to 6-in. round or square, and in qualities varying from plain carbon steel to alloyed steel. The alloys are, so far, principally nickel, vanadium and chromium. Our ingots vary in weight from 80 to 850 kilograms (176 to 1875 lb.). To enable the forging of the ingots in small quantities as we are producing, we use hammers and a 500-ton hydraulic press built at our plant. With this press, we can forge ingots up to 16-in. diameter and up to 2 tons. All shafts and worms of our elevator machines are now forged from our own steel.

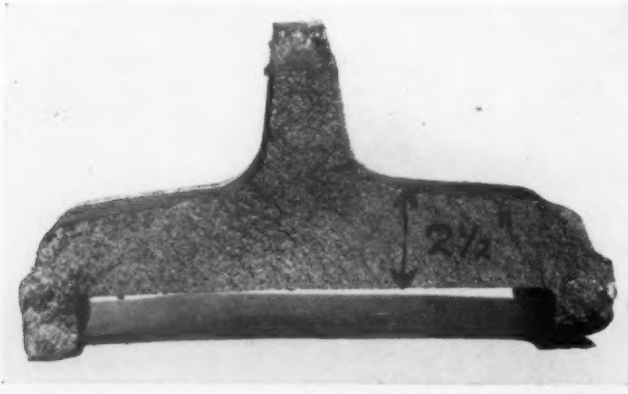

FIG. 4—UNIFORMITY OF GRAIN STRUCTURE IN AN ELECTRIC FURNACE GRAY IRON CASTING.

REFRACTORIES

12. After some years of experience with different refractories for our electric-arc furnace, we have attained good results with 100 per cent local refractories of silica for the roof and side walls and zirconium for the bottom.

Western Hemisphere Foundry Congress—V

Some Aspects of the Cast Iron Practice in Brazil

By Miguel Siegel*, Sao Paulo, Brazil

Abstract

This paper was presented to give an idea of the foundry practice in Brazil and touches on molding, sand practice, core practice and patternmaking methods used. The author discusses the new trend toward technical experiment and control in Brazil. He explains the functions and activities of the Instituto de Pesquisas Technologicas (Institute for Technological Research) with which he is connected and the successful results obtained by its foundry department, such as systematic study of local sources of foundry sands and improvement in cast iron quality. He then tells of the special castings which are produced by the Institute's foundry department in line with its purpose of illustrating modern foundry practice for the advancement of industry.

Development of Foundry Industries in Brazil

1. Brazil, the largest country in the Western Hemisphere, is destined to become one of the world's largest industrial countries, once its natural resources are fully developed. At the present time, although some states are rapidly becoming industrialized, Brazil is still largely agricultural and cattle-raising. The main industrial center of the country, Sao Paulo is, in fact, the largest industrial center in the whole of South America, more than one hundred of the largest and most modern foundries being located there.

2. Isolated foundries have been established all over the country to fulfill the needs of local industries. For example, cast iron foundries, capable of handling castings up to 10 tons, such as sugar mill rolls, may be encountered near the sugar mills in the north. In the central section, and more particularly in the State of Minas Geraes, where most of the blast furnaces and steel mills are located, the existing foundries are engaged in the production of ingot molds and maintenance castings for these plants. Toward the south, in the States of Rio de Janeiro, Sao Paulo, Parana, Santa Catarina, Rio Grande do Sul and the Federal District, one finds the bulk

* Chief of Scientific Service, Head of the Foundry Department of the Instituto de Pesquisas Technologicas.

Note: This paper was presented before the First Western Hemisphere Foundry Congress at the 46th Annual A.F.A. Convention, April 20, 1942.

FIG. 1—MAIN FLOOR OF THE CAST IRON AND MALLEABLE FOUNDRY OF CIA. LIDGERWOOD INDUSTRIAL, SAO PAULO.

of the foundries engaged in the production of general castings for railroads, for heavy machinery, for utility purposes and for farm and farm products machines.

3. Most of the foundries in Brazil lack modern and expensive equipment, due in part to the high cost of imported machinery and the scarcity of necessary capital, and in part to favorable labor conditions which explain the great preference given to manual labor in the operation of these foundries. Some foundries, however, such as those of the Light and Power Company in Rio de Janeiro and the Companhia Lidgerwood Industrial in Sao Paulo, which were established more than 15 years ago, have all the standard equipment used at that time, consisting in the main of American-made machinery. A trend towards mechanized foundries, carefully planned and located in adequately planned buildings, is rapidly developing and may be exemplified by both the Atlas Foundry of Sao Paulo which produces cupola and electric furnace iron, and the Bardella S. A. Foundry.

CAST IRON FOUNDRY PRACTICE IN BRAZIL

Melting Practice

4. In Brazil, as all over the world, the bulk of the cast iron pro-

duced is melted in the cupola. Cupolas imported from Europe and the United States years ago are being copied locally and others are designed and built according to literature. Since such furnaces must be adapted to local conditions and existing buildings, often unfit for the purpose, most cupolas present large diameters combined with low charging door and stack heights, are often provided with complicated tuyere design and, as a general rule, are equipped with undersize low pressure centrifugal blowers.

5. The most widely produced metal is regular soft gray iron, often of unbalanced composition, which goes into all kinds of miscellaneous and machine castings. The graph of Fig. 3 shows the range of tensile strengths obtained from control tests performed in the I.P.T.[1] on test bars conforming to A.S.T.M. standards and represent average commercial gray irons produced for castings for which mechanical strength is specified. Most of the specifications adopted call for a minimum of 14 kg. per sq. mm. (20,000 lb. per sq. in.) tensile strength.

FIG. 2—MAIN FLOOR OF CAST IRON FOUNDRY OF BARDELLA S.A., SAO PAULO.

[1] Throughout this paper the designation I.P.T. is used in referring to Instituto de Pesquisas Technologicas do Estado de Sao Paulo (Institute for Technological Research). It is an official institution, partially endowed by private industry, devoted to the promotion of technical aid to industries and engineering activities and serving as the official testing laboratory for the state of Sao Paulo. It started about 40 years ago as a laboratory for testing materials of the Polytechnic School of Sao Paulo and has developed into a nationally known institution which includes 12 main departments and a staff of 200 men of which more than 50 are graduate engineers and chemists.

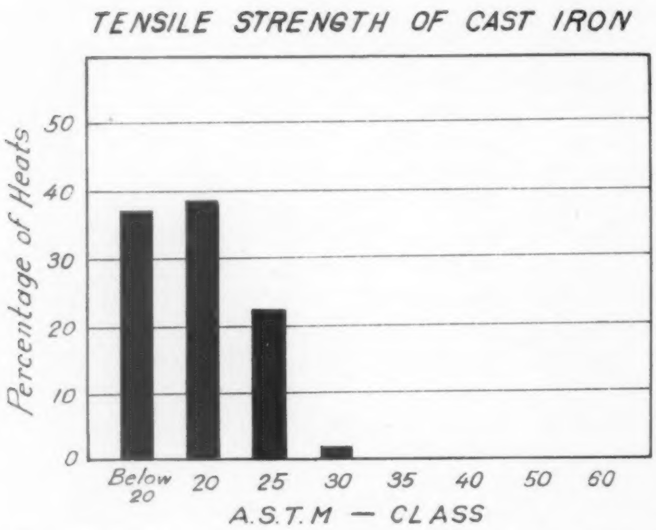

FIG. 3—TESTS OF CUPOLA CAST IRONS PRODUCED BY AVERAGE BRAZILIAN COMMERCIAL FOUNDRIES.

6. Cupola charges are made up of (1) pig iron, (2) bought miscellaneous scrap and (3) sprues, risers and rejected castings. The pig iron used is charcoal pig iron produced in Brazil. Compositions of charcoal pig vary according to producer and in many cases vary from lot to lot, as shown in Table 1. Selected cast iron scrap, such as motor scrap, is difficult to find in sufficient quantities. Most common scrap is miscellaneous scrap made up of heavy machine scrap and light utility castings mixed with some motor scrap. Steel scrap is used by few foundries, and then only in small quantities up to about 10 per cent.

Table 1

COMPOSITION OF BRAZILIAN PIG IRON

Producer	*Total Carbon, per cent*	*Silicon, per cent*	*Manganese, per cent*	*Phosphorus, per cent*	*Sulphur, per cent*
A	3.6-3.9	2.15-3.31	0.10-0.35	0.17-0.19	0.013-0.09
B	3.6-3.7	2.80-4.50	0.16-0.45	0.36	——
C	——	1.50-2.60	0.06-0.12	0.30	0.09
D	——	1.65-2.66	0.09-1.48	——	——
Synthetic pig iron	2.7-3.9	1.89-3.20	0.33-1.00	0.024-0.21	0.011-0.093

7. The coke used, up to the present time, is foundry coke imported mainly from England. Recently, some American coke has been imported, but foundrymen claim that English coke provides better metal temperatures at lower percentages. Small quantities already are being produced locally with imported coals, but due to the scarcity of good foundry grades, low quality coke produced by gas companies is being used by many foundries.

8. Under present conditions, large scale cupola operation is becoming more and more difficult and iron costs have increased from 4 cents to 8 or 9 cents per kg. (about 2 lb.) at the spout. Imported foundry coke, when available, sells for $60 a ton and pig iron and scrap prices have gone up nearly 100 per cent. Oil-fired crucible and rotary furnaces, used for producing small quantities of cast and malleable iron, are operating at reduced capacities due to the rationing of fuel oils.

9. A solution, whereby low-grade Brazilian coals or charcoal may be used, is being sought and such have been tried in air furnace operation in experiments effected in this country. A special type of air furnace was developed by an American company which makes possible the efficient burning of mixtures of low and high grade coals by adjusting their proportions as needed during operation. One such furnace has already been installed at the Companhia Brasileira de Usinas Metallurgicas in Rio, and more foundries are

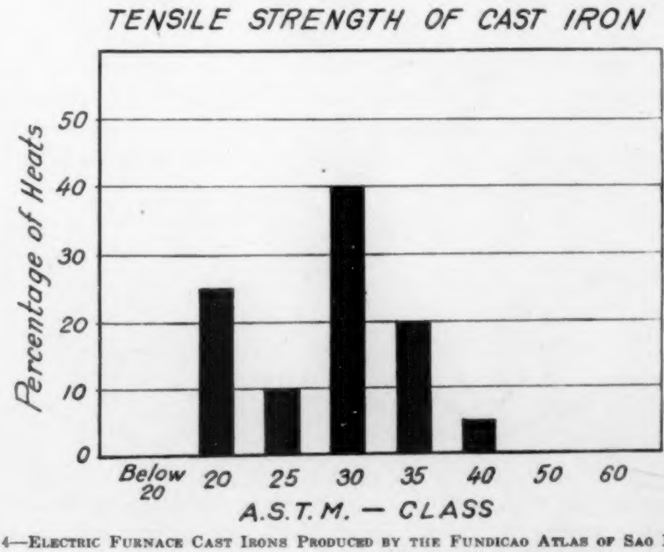

FIG. 4—ELECTRIC FURNACE CAST IRONS PRODUCED BY THE FUNDICAO ATLAS OF SAO PAULO.

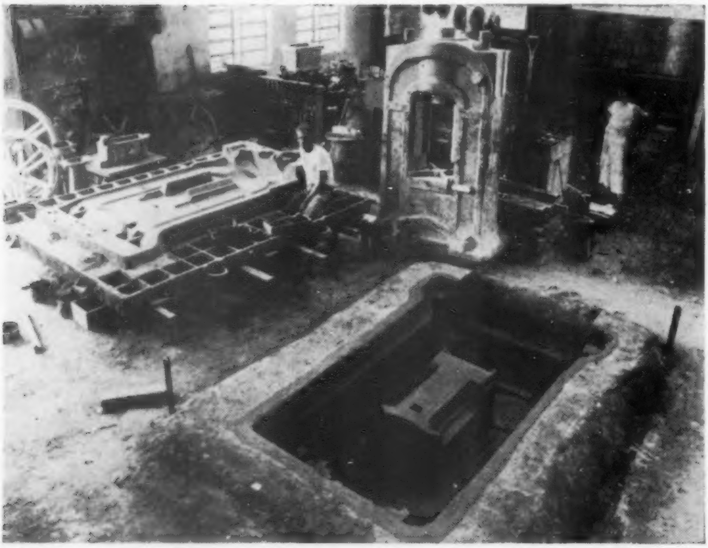

FIG. 5—MOLD FOR 125 TON CAPACITY PRESS FRAME WEIGHT OF CASTING 6000 KG. (13,200 LB.). CAST OF 2.0 PER CENT NICKEL AND 0.6 PER CENT CHROMIUM CUPOLA CAST IRON BY BARDELLA S.A.

contemplating the installation of this type of furnace.

10. Formerly some electric furnace iron was made occasionally in installations intended for steel. With the present situation, electric furnace iron may be produced at costs which compare favorably to the ones of irons melted in fuel furnaces. Recently, one foundry has been set up for the purpose of producing high-grade electric-furnace iron for elevator castings. This foundry operates a 3 ton direct-arc type "Brown Bovery" furnace and specializes in the production of high quality castings, for both its own use and trade. (See Fig. 4.)

11. The advantages of higher grade irons are being gradually accepted by both foundrymen and customers and, with the assistance of the I.P.T., foundries in a position to furnish high-strength castings are appearing in an ever increasing number.

Molding Practice

12. Most of the molding is done by hand by skilled practical molders. Here the skill of the molder is of paramount importance for the production of good castings, since the available equipment is either scarce or worn. Tight-fitting flasks are seldom to be

found, and patterns, furnished by customers, are often treated without the proper care by molders, making efficient production of castings difficult. Following the customary practice, large molds are usually made in dug-out pits on the floor, large and expensive flasks usually being scarce (Fig. 5).

13. Some foundries are equipped with molding machines which are used for production work, most of them being hand-operated, squeeze-type machines. Nevertheless, compressed air-operated, jolt-squeeze, jolt-squeeze stripper, and jolt roll-over machines are to be found, but can seldom be operated at best efficiency due to lack of enough production work. Most of the molds turned out on these machines are made in regular flasks, cope and drag made separately. Snap-flasks and slip-flasks are rapidly gaining favor due to savings in flask equipment (Fig. 4).

Sand Practice

14. Natural bonded sand has been used exclusively for gray iron molding until recently. The sands available in the Sao Paulo region are bank sands originating from relatively recent rock alterations. Properties of the preferred sands are given in this paper.

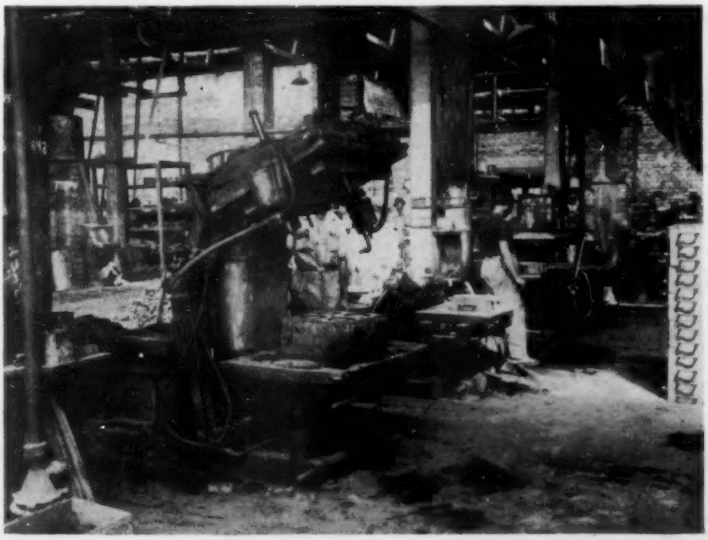

FIG. 6—JOLT-SQUEEZE AND JOLT-ROCKOVER MACHINES AT WORK AT THE FOUNDRY OF CIA. LIDGERWOOD INDUSTRIAL.

FIG. 7—CAST IRON HERRING-BONE GEAR WEIGHING 1400 KG. (3100 LB.) CAST BY CIA. LIDGERWOOD INDUSTRIAL.

15. Sands used are far from ideal for green molds, which accounts for the extensive dry sand molding practiced. Sintering points are also low. Such deficiencies have caused foundries, willing to improve their practice and castings, to adopt synthetic foundry sands as a result of experiments effected by the I.P.T. foundry department and corroborated by practical results. More general use of synthetic sands is hindered by a general lack of sand preparation equipment and of sources of supply of uniform washed sands and proper clays. Composition and properties of adopted mixtures are given in this paper.

Core Practice

16. Cores are also made by hand by experienced core makers. Elaborate core box design is seldom used and difficulties are left to the core maker. The cores are made of clay bonded (generally natural bonded) and oven dried sands. Difficult cores often take patented core binders, manufactured locally, which are added to

the clay bonded sand. Dextrine and molasses are also used by some foundries. Linseed oil, being rather expensive, is used only in progressive foundries making better castings, its use being limited to small cores in the average foundry. Local manufacture of core oils, higher grade core-binders, mixed washes and blackings is non-existent.

17. Binders are not used to best advantage since ovens are wood-fired and not provided with temperature control devices, making proper drying impossible.

Patterns

18. Limited numbers of skilled pattern makers and good pattern making shops may be found in Brazil. If one is willing to pay well for the job, one can obtain well-made wooden patterns, properly split, with properly fitted bosses, and core-prints and with adequate drafts. However, to effect savings, many foundries or their

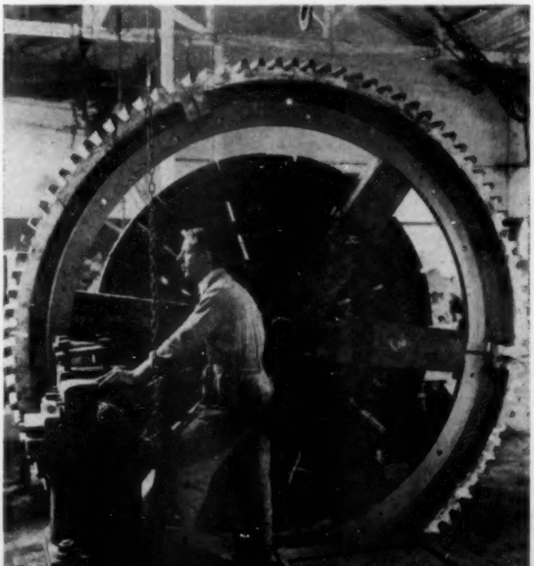

FIG. 8—CAST IRON GEAR 3.0 METERS (10 FT.) IN DIAMETER WHICH WAS CAST IN THREE PARTS. TOTAL WEIGHT 4500 KG. (10,000 LB.). CAST AND MACHINED BY MAQUINAS PIRATININGA LTDA.

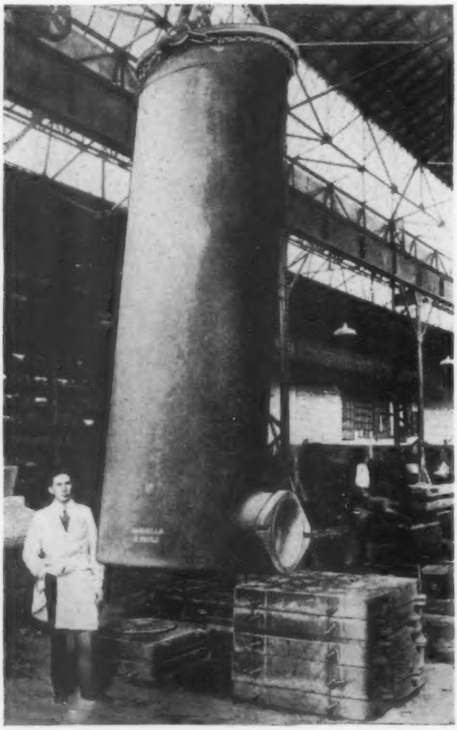

FIG. 9—CAST IRON RETORT USED FOR THE PRODUCTION OF CARBON SULFIDE. WEIGHT IS 7000 KG. (15,800 LB.). CAST BY BARDELLA S.A.

customers have their patterns made by expert cabinet makers, the result being a nice looking pattern but one which is rather troublesome for the molder.

19. Pattern plates for machine molding are often cast in aluminum or made up of white metal parts mounted on steel plate. A few shops specializing in metal patterns do turn out fine work.

Castings Produced

20. As already stated, foundries are engaged in most diversified jobs, the same shop being compelled to turn out both small and large castings. In view of the often deficient means and equipment, one is surprised at the fine castings to be seen in some of the better foundries. Such results are possible only because of the long experience of practical foundrymen in charge of the shops (Figs. 7, 8 and 9). Technical foundrymen, however, being very scarce,

progress in metal composition and improvements of melting and molding practice are not to be expected in the average foundries, where control of metal analyses and temperatures and of sand properties are not practiced, the only available instrument being the "experienced eye."

21. Advanced jobbing foundries turn out higher strength cast iron machine castings either in the cupola, with the addition of higher percentages of steel, or with addition of small amounts of alloys such as nickel, and chromium or in the electric furnace where synthetic iron is produced. Such foundries practice control of both the raw material and the finished product, either through their own laboratories or official ones. In some fields, one may find production foundries turning out standard products, such as enamelled sanitary and cooking utensils. Two of the main production foundries in Sao Paulo turn out more than 100 tons of such castings a month.

NEW TRENDS IN THE FOUNDRY PRACTICE IN BRAZIL

22. As already noted, the foundries in Brazil have been run largely by practical men, and even large machine shops, when directed by technical men or graduated engineers, have left their foundries to the care of the practical foreman. The main reason for this situation is the scarcity of technical foundrymen and

FIG. 10—MAIN FLOOR OF THE I.P.T. EXPERIMENTAL FOUNDRY.

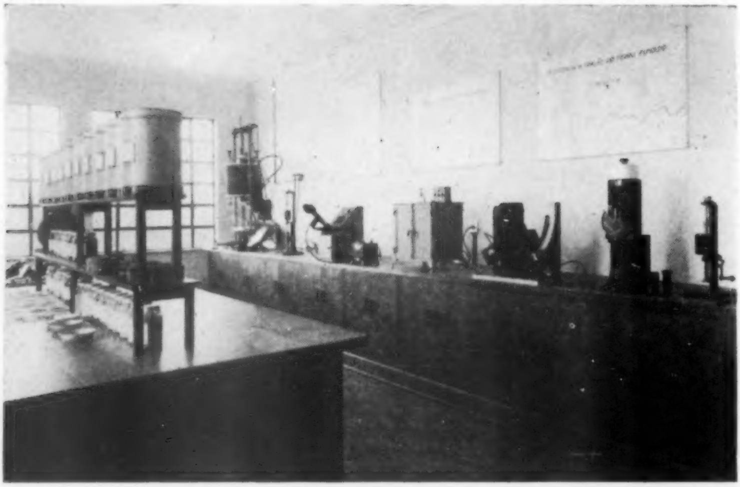

FIG. 11—VIEW OF SAND TESTING LABORATORY OF THE I.P.T. FOUNDRY DEPARTMENT.

metallurgists. On the other hand, very few foundries can afford laboratories and experimental installations, and thus the services of such technical men are seldom completely successful.

23. To make available both services and experimental installations and laboratories, the I.P.T. undertook to install an experimental foundry which, in addition to the already existing chemical, metallographical and metal testing departments, is to serve as an experimental station for the improvement of foundry practice. This foundry covers 11,000 sq. ft. of concrete structure building and is equipped with $75,000 worth of modern American equipment, imported at the beginning of last year.

24. The melting department consists of one one-ton capacity direct-arc furnace, one 500 lb. capacity indirect-arc rocking furnace and one No. 2 cupola lined to 22-in., complete with automatic air control device. The sand preparation equipment includes a complete muller-type sand mixer with vibrating sieve, magnetic separator, rotoclone for fines control and aereator, one muller-type mixer for core sands and a complete sand testing laboratory. There are also two American-made molding machines, one of the jolt-squeeze and the other of the jolt-rockover type. The cleaning room includes a 10 ft. x 10 ft. sandblast room, a sandblast cabinet and tumbling barrel, all properly exhausted. The foundry also includes a welding unit and an electric heat-treating furnace. The main floor is served by a 5-ton crane (Fig. 10).

25. The activities of this new department may be classified as follows:

(1) To serve as technical advisor to foundries and dependent industries.

(2) To serve as a model foundry for industry.

(3) To undertake the training of technical and practical foundrymen for industry.

(4) To undertake the research of foundry problems, either of general interest or when requested by private industry.

(5) To undertake the production, on a small scale, of special castings and metals, not produced by regular foundries, when requested by government departments or private industry.

26. The department has been providing technical assistance to foundries since 1939. The experimental foundry has been in regular operation since the middle of last year.

SUCCESSFUL RESULTS OBTAINED BY THE I.P.T. FOUNDRY DEPARTMENT AS A TECHNICAL ADVISOR

Systematic Study of Local Sources of Foundry Sands

27. In view of the deficiencies observed as to the molding sands used in most of the cast iron foundries, the foundry department, through its sand testing laboratory, is undertaking the testing of samples of sands used in several cast iron foundries (Fig. 11). Typical properties of green natural bonded used molding sands are shown in Table 2. Low permeability, high moisture and clay content and impurities make such sands responsible for defective castings, which are generally coated with burnt sand, hard to remove, particularly in the case of heavy castings.

Table 2

PROPERTIES OF USED NATURALLY-BONDED MOLDING SANDS

	A[1]	*B*[1]	*C*[1]	*D*[2]	*E*[3]
Moisture, per cent	10.0	10.4	12.7	11.5	8.8
Green permeability	15	27	20	17	7
Green strength	7.5	8.5	9.0	13.0	6.5
Dry permeability	—	—	—	—	8
Dry strength	—	—	—	—	24

1 Used for small and medium gray iron castings.
2 Used for small gray iron castings.
3 Used for small and medium malleable castings.

28. Tests of new naturally-bonded sands most widely used by local foundries, in the vicinity of Sao Paulo, show unfavorable grain distribution and shape, and high percentage of fines and clays low in bonding strength. Impurities of low fusion point, such as feldspar and microscopic mica, are also to be found and influence the sintering point unfavorably. Properties of naturally-bonded sand most widely used in Sao Paulo are given in Table 3.

Table 3

PROPERTIES OF NEW NATURALLY-BONDED SAND

Fineness Test	
Screen	*Per Cent*
6	—
10	0.6
20	0.2
28	0.5
35	0.4
48	0.8
65	5.2
100	16.6
150	21.0
200	17.2
270	6.0
Pan	13.2
Clay content	18.2
Grain fineness number	135
Green Sand Tests	
Moisture, per cent	10.0
Permeability	15
Green strength	10.5

29. As supplies of naturally-bonded sands better suited for cast iron molding are not known in the vicinity, synthetic molding sands are recommended by the I.P.T. to foundries willing to improve their sand practice. Two types of green sand generally are used by the average foundries which use all facing sand practice, fine sand for small castings up to about 50 lb., and coarser sand for larger castings. Dry sand and oil sand are used for heavy castings and for castings that require smooth finish (Table 4). Practical results obtained with such sands in several commercial foundries have directed the attention of foundrymen toward the importance of molding sands in the foundry.

30. The main difficulty for the widespread use of synthetic sands in the average cast iron foundries is the lack of proper sand

preparation equipment. However, existing equipment, adequately adapted has been yielding satisfactory results. More progressive foundries are gradually accepting the idea that money spent on sand equipment and control pays dividends.

Table 4

COMPOSITIONS AND PROPERTIES OF SYNTHETIC MOLDING SANDS USED FOR CAST IRON MOLDING

	Fine Sand	*Coarse Sand*	*Dry Sand*	*Oil Sand*
Fine beach sand, per cent	80	—	—	—
Coarse beach sand, per cent	—	—	—	96
Coarse bank sand, per cent	—	80	85	—
Clay, per cent	15	15	15	—
Sea coal, per cent	5	5	—	—
Linseed oil, per cent	—	—	—	2
Dextrine, per cent	—	—	—	2
Moisture, per cent	4.5-6.5	4.5-6.0	7.0-8.0	1.0-2.0
Green permeability	30-40	40-50	65-85	100-150
Green strength	7.5-10.0	8.5-10.5	6.5	2 max.
Dry permeability	—	—	90-100	150-200
Dry strength	—	—	90 min.	300 min.
Dry tensile strength, lb. per sq. in.	—	—	—	120-150

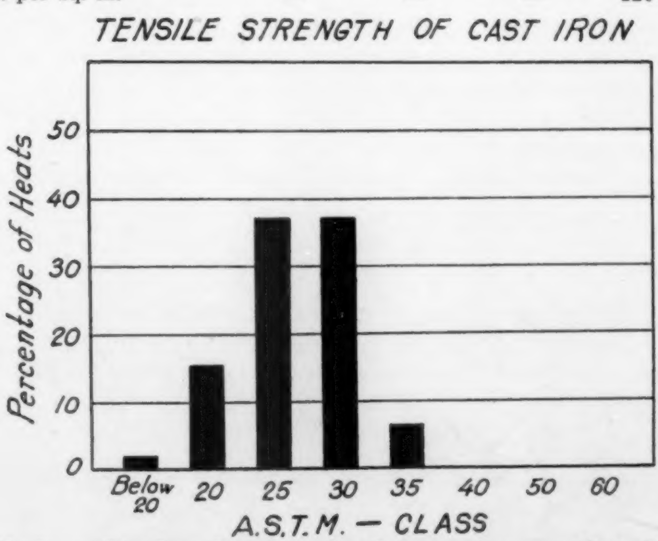

FIG. 12—CUPOLA CAST IRONS PRODUCED BY CIA. LIDGERWOOD INDUSTRIAL AFTER CONTROL TESTS AND ANALYSES WERE INTRODUCED BY I.P.T.

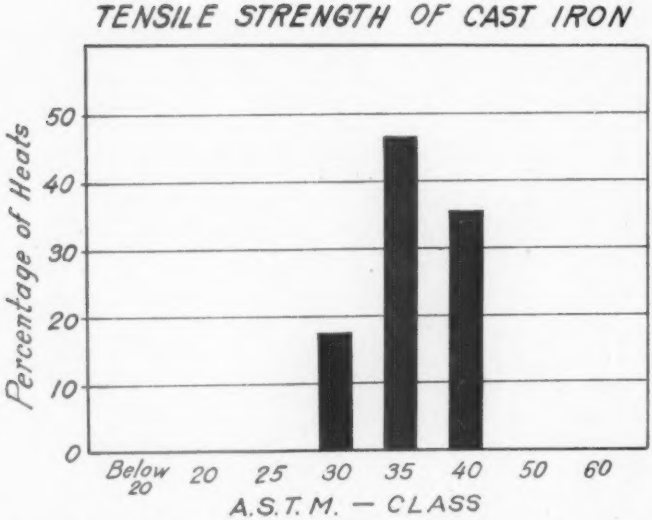

FIG. 13—HIGH-STRENGTH CUPOLA CAST IRONS PRODUCED BY MAQUINAS PIRATININGA LTDA. UNDER THE SUPERVISION OF THE I.P.T. FOUNDRY DEPARTMENT.

Improvement of Cast Iron Quality

31. Another field of the foundry department's activities is the control of cast iron produced by commercial foundries, with the purpose of improving quality and foundry practice. One instance is the systematic analyses and physical testing of cast iron carried on by the Companhia Lidgerwood Industrial, which produces machine castings up to 10 tons in weight, some of which require high-strength and close-grained iron of good machinability. The castings originally produced by this company presented the average analyses and properties shown in Table 5.

Table 5

ANALYSES OF HIGH-STRENGTH, CLOSE-GRAINED IRON

Tensile Strength, lb. per sq. in.	*Brinell Hardness*	*Total Carbon, per cent*	*Silicon, per cent*	*Manganese, per cent*	*Phosphorus, per cent*	*Sulphur, per cent*
20,000	150	3.50	1.8	0.2	0.2	0.08

32. Although tensile strength of original cast iron produced was considered satisfactory, machinability of smaller castings was difficult, the cause being the presence of free cementite. After the adjustment of composition, the tensile strength was definitely im-

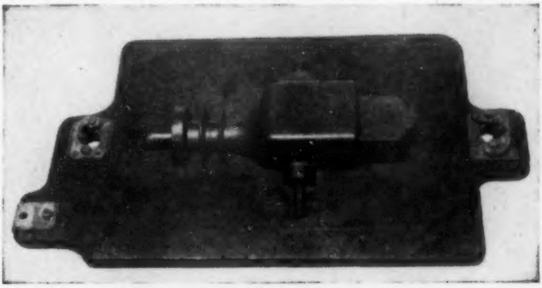

FIG. 14—WOODEN PATTERN PLATE USED FOR SMALL SCALE PRODUCTION.

proved, as shown by the graph of Fig. 12, and hardness increased to 180-200 Brinell with improved machinability.

33. Another example is the direct assistance of the department's technical men in the production of special cast irons or castings in local foundries. Such a job was undertaken for the Maquinas Piratininga Ltda., which is engaged in the production of special castings of high-strength cupola iron. The selection of materials, calculation of charges, adaptation of existing equipment, and the actual melting of the first several heats was made under the supervision of the I.P.T. foundry department, at the company's foundry. A report was presented which contained complete in-

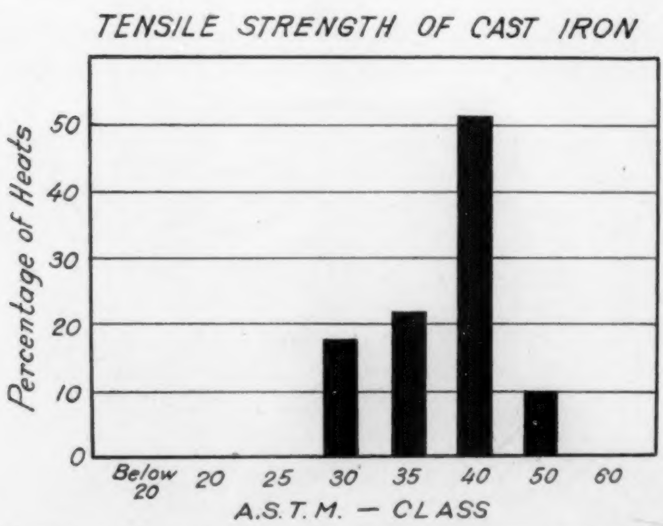

FIG. 15—ELECTRIC FURNACE CAST IRON MADE BY I.P.T. FOUNDRY. GRAPH REPRESENTS ABOUT 200 DETROIT FURNACE HEATS.

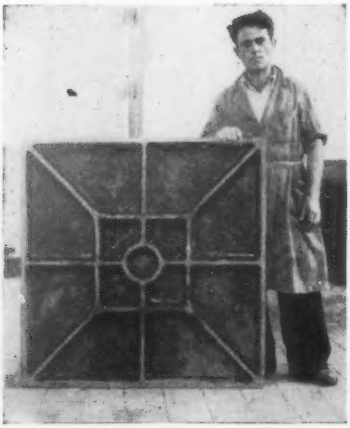

FIG. 16—PLATE FOR SOIL COMPRESSION TESTS WEIGHING 385 KG. (850 LB.), WHICH WAS MADE OF ELECTRIC FURNACE CAST IRON, SHOWING 32 KG. PER SQ. MM. (45,000 LB. PER SQ. IN.) TENSILE STRENGTH.

formation enabling the company to proceed with production independently. The control of these special heats is still being made by the I.P.T. through analyses and physical tests. Tensile strengths of such cast iron are given in the graph of Fig. 13.

PRODUCTION OF SPECIAL CASTINGS BY THE I.P.T. FOUNDRY

34. As already stated, the purpose of the experimental foundry is to illustrate modern foundry practice for the advancement of in-

FIG. 17—CAST IRON AUTO-PATROL WHEEL WEIGHING 280 KG. (600 LB.), WHICH WAS MADE OF ELECTRIC FURNACE IRON SHOWING 32 KG. PER SQ. MM. (45,000 LB. PER SQ. IN.) TENSILE STRENGTH.

FIG. 18—DRY SAND MOLDS AND GREEN SAND MACHINE-MADE MOLDS FOR LARGE AND SMALL COMPRESSOR CASTING RESPECTIVELY. MADE BY I.P.T. FOUNDRY.

dustry and to undertake production of special castings and metals when requested. Simultaneously, technical and practical foundrymen are being trained to lend their services to industry when such training is completed.

35. Every effort is being made to employ the most advanced practice possible, under local conditions. Synthetic sands are used exclusively and go through the mixer after every heat. Every batch of sand is tested for moisture, permeability and green strength.

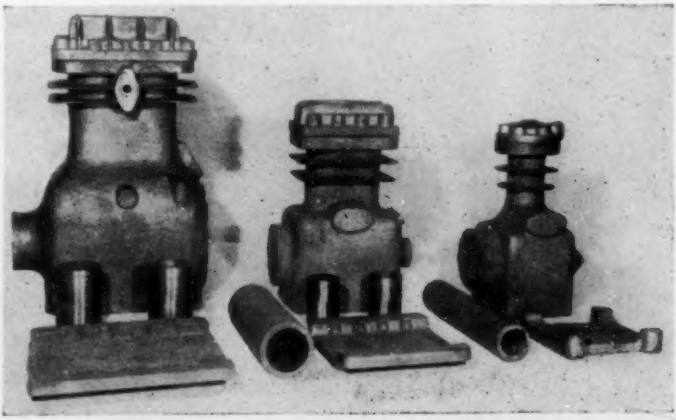

FIG. 19—COMPRESSOR CASTINGS PRODUCED BY I.P.T. FOUNDRY.

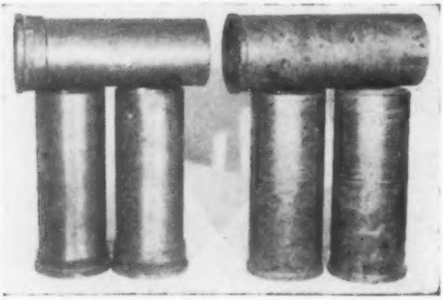

FIG. 20—CENTRIFUGAL CAST IRON AUTOMOTIVE CYLINDER LINERS BEFORE AND AFTER MACHINING. MADE BY I.P.T. FOUNDRY.

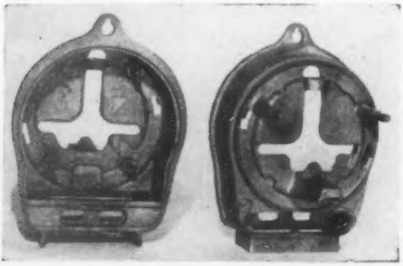

FIG. 21—CAST IRON ELECTRIC WATT-HOUR METER BASE, PRODUCED ON MOLDING MACHINE IN SLIP-FLASK MOLDS.

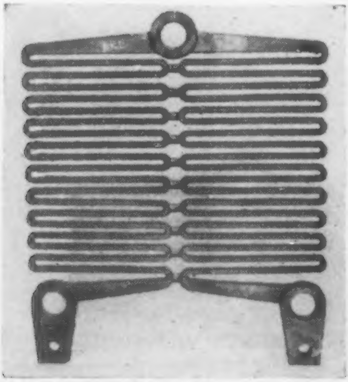

FIG. 22—ALLOY CAST IRON ELECTRICAL RESISTANCE GRID MADE BY I.P.T. FOUNDRY.

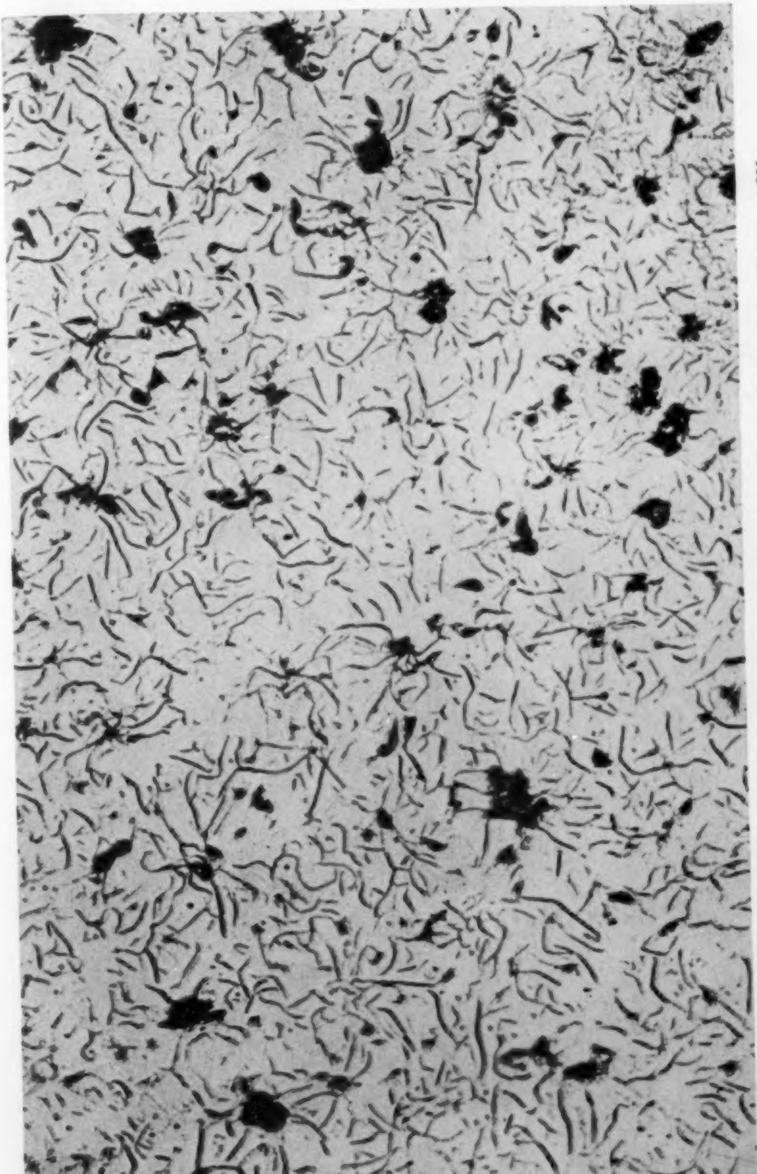

FIG. 23—PHOTOMICROGRAPH OF CAST IRON RESISTANCE GRID CONTAINING 4.5 PER CENT NICKEL. x200.

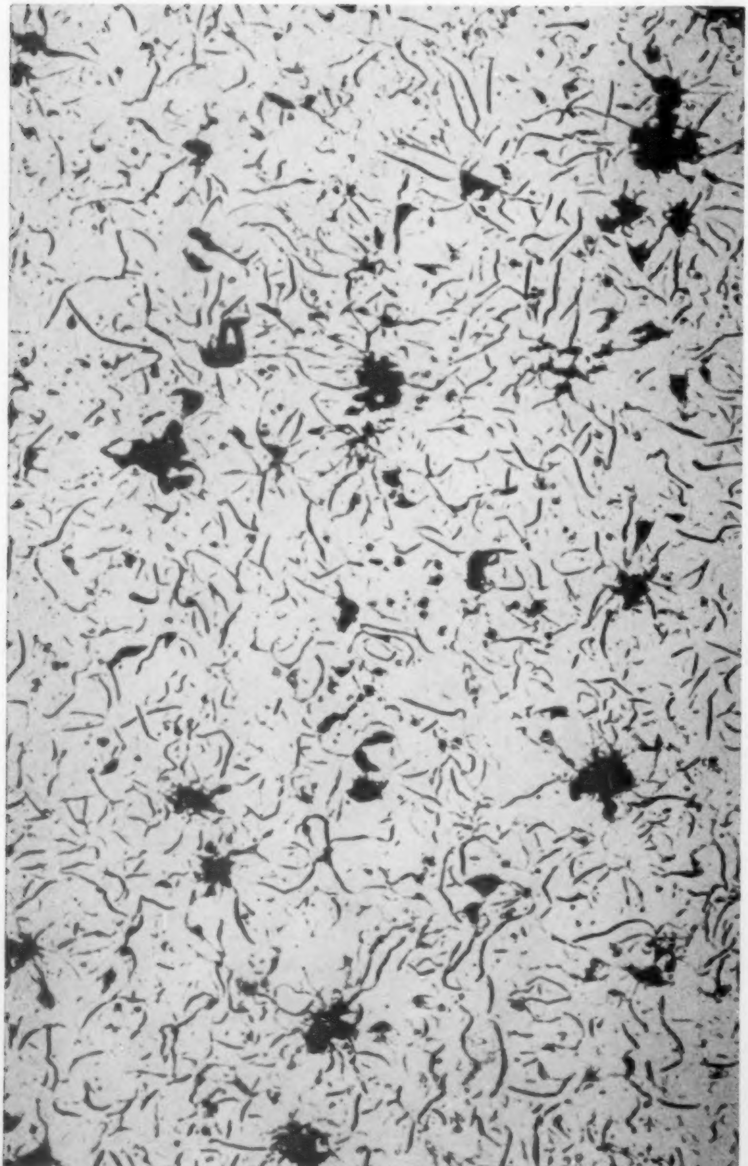

FIG. 24—PHOTOMICROGRAPH OF CAST IRON RESISTANCE GRID CONTAINING 2.5 PER CENT COPPER. x200.

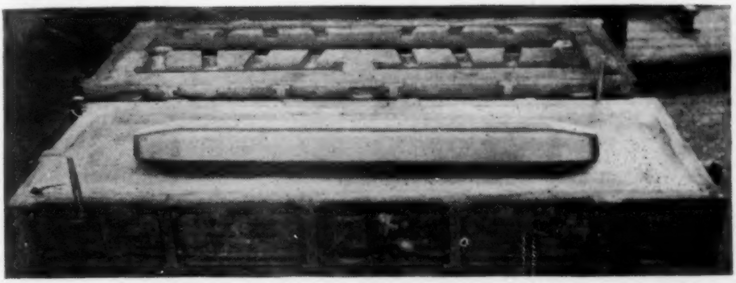

FIG. 25—DRY SAND MOLD WITH OIL SAND DRAG FOR CHROMIUM CAST IRON INGOT MOLDS.

Dry sand and core sand tests also are made regularly. All molding is made in flasks and demountable flasks are provided for this purpose. Machine molding is encouraged, even for small groups of castings, an inexpensive type of pattern plate having been developed, consisting of wooden patterns mounted on special moisture-resisting plywood which is yielding satisfactory results. One plate has already been used for more than 5000 castings, with minor repairs (Fig. 14).

High-strength Cast Irons

36. Castings calling for high tensile strength iron are cast of electric furnace pearlitic iron melted in the 500 lb. capacity indirect-arc electric furnace. The results obtained for all cast irons heats, where no special effort was made to obtain soft metal, are shown in the graph of Fig. 15. Castings weighing from 5 to 850 lb. have been cast of such irons which show 240-260 Brinell hardness and are perfectly machinable (Figs. 16 and 17).

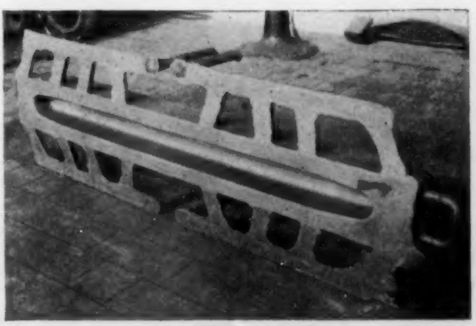

FIG. 26—CHROMIUM CAST IRON INGOT MOLD FOR COPPER INGOTS AFTER SHAKE-OUT WEIGHING 220 KG. (500 LB.).

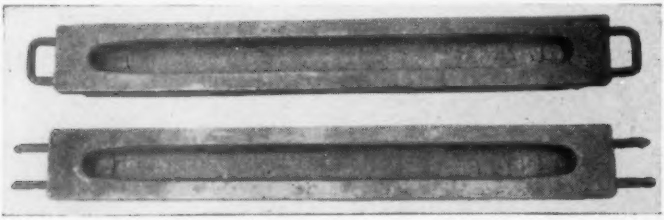

FIG. 27—CHROMIUM CAST IRON INGOT MOLDS AFTER BEING USED FOR ABOUT 500 COPPER INGOTS.

Pressure-tight Castings

37. Refrigeration compressors were imported mainly from the United States and were assembled in Brazil for commercial refrigerators. Due to importing difficulties, such machines are now being made locally and the I.P.T. foundry has been producing castings for same (Figs. 18 and 19).

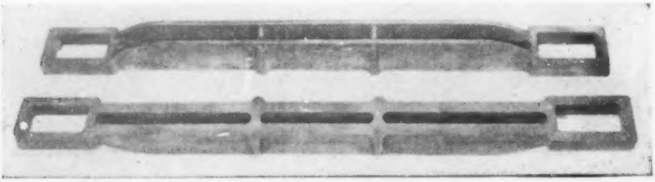

FIG. 28—CHROMIUM CAST IRON GRATE BARS FOR SILICA BRICK KILNS CAST BY THE I.P.T. FOUNDRY.

38. Cast iron presenting about 40,000 lb. per sq. in. tensile strength and 240 Brinell hardness, of 3.0 per cent total carbon, 1.8 to 2.0 per cent silicon, 0.6 per cent manganese, 0.3 per cent phosphorus and 0.1 per cent sulphur, is being used. Patterns had to be adapted to avoid excessive variation in section and to prevent cracking and hard spots. Such irons of low carbon and silicon content present improved weldability, making minor repairs possible.

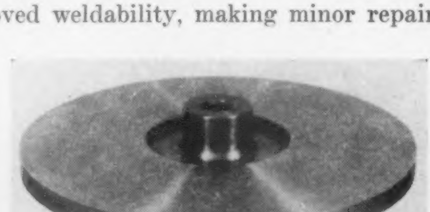

FIG. 29—CHROMIUM CAST IRON DIAMOND-CUTTING DISK MADE BY I.P.T. FOUNDRY.

FIG. 30—PHOTOMICROGRAPH OF IMPORTED CAST IRON DIAMOND-CUTTING DISK CONTAINING ABOUT 2.0 PER CENT PHOSPHORUS. ETCHED WITH PICRIC ACID. x500.

FIG. 31—PHOTOMICROGRAPH OF CHROMIUM CAST IRON DIAMOND-CUTTING DISK CONTAINING ABOUT 1.0 PER CENT CHROMIUM. ETCHED WITH PICRIC ACID. x500.

FIG. 32—NI-HARD SLEEVES FOR ROLL CRUSHER AND BOTTOM PLATES FOR PUG-MILL USED FOR CRUSHING SILICA STONE IN A REFRACTORY PLANT.

39. Production of centrifugally-cast cylinder sleeves for automobiles has been started at the request of a specialized machine shop engaged in motor repairs (Fig. 20). The casting machine, belonging to the customer, is operated by him, and the iron, of controlled composition and temperature, is furnished by the I.P.T. foundry at the furnace spout. Heat treatment is also under the supervision of the I.P.T. Composition used is 3.1 to 3.2 per cent total carbon, 2.70 per cent silicon, 0.6 per cent manganese, 0.3 per cent phosphorus and 0.1 per cent sulphur.

Soft Gray Iron

40. Special castings presenting thin section require soft gray iron at high pouring temperatures which is produced in the indi-

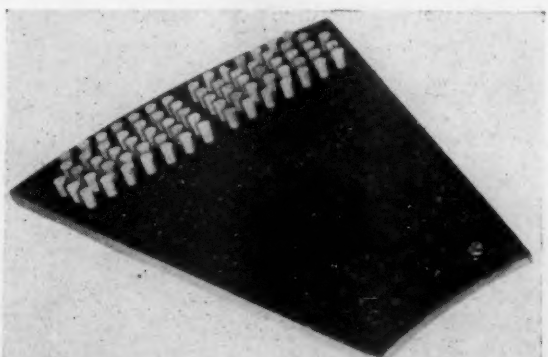

FIG. 33—PATTERN FOR PUG-MILL BOTTOM PLATES SHOWING PART OF CORES SET UP AS USED FOR GREEN SAND MOLDING.

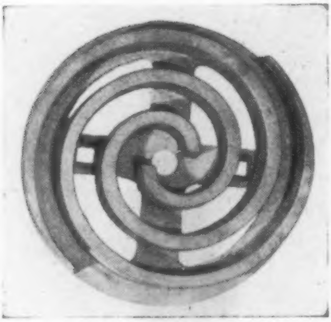

FIG. 34—NI-HARD DISK FOR POLISHING STONE MADE BY THE I.P.T. FOUNDRY.

rect-arc electric furnace. One instance is a watt-hour meter base casting which presented sections less than 1/16-in. thickness and which had to be machinable (Fig. 21). An attempt was made to produce such castings in machine-made slip molds, the casting being contained in the cope, and 200 castings were made. However, due to the molding practice and to defects of pattern, which was furnished by customer, the percentage of offset castings was rather large. Another instance is an electrical resistance grid used for electric trolleys. The pattern plate was designed and made by the I.P.T. in conformance with grid design already used by customer (Fig. 22). Several grids were cast, at first of irons of various compositions. Electrical resistance tests showed that higher resistance was obtained when flake graphite is present rather than with dendritic distribution. In the case of electric furnace iron, to obtain soft iron in such light sections, the addition of either nickel or copper proved advantageous (Figs. 23 and 24).

FIG. 35—GROUP OF NI-RESIST CASTINGS FOR PASTEURIZING MACHINES.

FIG. 36—NI-RESIST CASTINGS FOR GAS-FLOW MEASURING APPARATUS.

Low Alloy Cast Iron

41. Low chromium cast irons have been recommended by the department for both heat and abrasion resistance applications. One per cent chromium cast iron ingot molds were made for the production of copper ingots (Figs. 25 and 26). These molds have already yielded twice as many ingots as the originally used plain iron molds and are still in use. The two first molds made (Fig. 27) are still repairable after more than 500 ingots.

42. To assure good finish of ingots, the working surface was molded of an oil sand mixture, oven dried and coated with graphite wash. Resulting castings were smooth and merely had to be brushed.

43. Chromium grate bars also have been supplied for high temperature silica brick kilns (Fig. 28).

44. A study of cast iron suitable for diamond cutting disks was undertaken. Chemical and micrographic examination of imported disks showed high phosphorus content and areas of hard steadite. As high phosphorus iron was not available, chromium cast iron

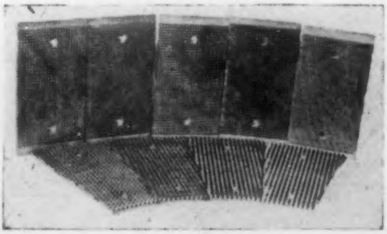

FIG. 37—NI-RESIST CASTINGS FOR ORANGE OIL EXTRACTION MACHINE.

disks were tried and such disks, with a 300 to 350 Brinell hardness, presented improved cutting efficiency and wear resistance and used less diamond powder when compared with imported disks (Figs. 29, 30, 31).

Alloy Cast Irons

45. Ni-hard castings have been recommended and cast for several high-duty purposes. For the production of silica refractory brick, cylinder crusher rolls and pug mill, bottom plates were made (Fig. 32). Pug mill plates were cast in green sand, and cores for the necessary tapered holes were set into pattern prior to molding (Fig. 33).

46. Ni-hard disks for the polishing of stone and marble also are being tried in service (Fig. 34). All castings were cast in sand and presented over 500 Brinell hardness. Ni-resist castings are being made for several purposes.

47. Two per cent chromium Ni-resist was used for castings for pasteurizing equipment. Formerly bronze castings were used, which had to be tinned, in the working surfaces. A set of diaphragms for measuring gas flow also was made (Figs. 35 and 36). Another application of Ni-resist is for castings used for orange oil extraction machines. Such castings made of 4 per cent chromium Ni-resist are cast in green sand machine-made molds and teeth have to be sharpened by grinding in view of their high hardness (Fig. 37).

Atmospheric Pressure and the Steel Casting—A New Technique in Gating and Risering*

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Washington, D. C.

Abstract

The proper use of risers in the manufacture of metal castings has presented a major problem, continually taxing the ingenuity of every foundryman. However, the last few years have led to studies of ideas and theories advanced by foundrymen. This is particularly true of the practice of feeding steel castings by means of "blind risers." In this paper the authors discuss theories and their experimental work on principles governing the action of atmospheric pressure in feeding castings and indicate how advantage may be gained by applying this knowledge. They first discuss the developments leading up to the use of the Williams head. Then they review theoretical considerations. Laboratory experiments were conducted to test the validity and practical value of the reasonings involved, with data being presented on comparisons of the physical properties of steel castings fed by means of open and blind risers. Foundry considerations in the use of the blind riser are dealt with in detail as are the practical features of the method. The authors conclude their paper with examples of commercial castings made by this method.

Introduction

1. The proper use of risers, often called "shrink heads" or "feed heads," in the manufacture of metal castings presents a problem which is continually taxing the ingenuity of every foundryman. The size, position, type, and number vary with every

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** Division of Physical Metallurgy, Naval Research Laboratory.
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new job and must be determined before the mold can be made. Each different casting is generally a problem in itself embodying principles of molding which must necessarily be decided in the light of individual experience.

2. Besides being essential to the internal soundness of the casting, risers also greatly influence the cost of the finished article. Frequently this factor alone determines whether a particular casting can be made economically in a given shop at prevailing market prices. The size of risers used may vary from 10 per cent of the total casting weight in one case to 70 per cent in another, depending partly on the experience of the foundryman, but to a much greater extent on the design and size of the particular casting.

3. These risers must be removed and the casting shaped to the proper contour before being shipped to the consumer. Thus, the position of risers and the area of contact between the riser and the casting is important. Also, since the size and number of risers determine the amount of metal in excess of that comprising the casting proper, it is clearly desirable to use as few and as small risers as possible commensurate with the soundness of the casting.

4. Technical development has not yet progressed to the point where one set of rules can be applied to all jobs, and except for a few basic principles, the manner of "risering" is still largely by "rule of thumb." It is common to err on the safe side by using an excessive size and number of risers, since losses incurred in this manner are less noticeable and normally less costly than a casting scrapped because of insufficient feeding.

5. The last few years have wrought great changes in steel-making and particularly in the manufacture of steel castings. Many ideas originally thought to be impractical have led directly to techniques of great advantage to the foundryman.

6. Falling in this category is the development of a satisfactory method of feeding steel castings by means of a "blind riser." Such a riser may be defined as one which does not extend through the cope, or upper part of the mold, but is surrounded completely by sand, and which may be placed at any point within the mold. Experiments with this type of riser have brought about a realization of the important part played by atmospheric pressure in the founding of metals. It is the purpose of this paper to discuss, in the light of experimental evidence, the principles governing the action of atmospheric pressure in feeding castings and to indicate how advantages may be gained by applying this knowledge.

HISTORICAL

7. "Blind risering," in its broader aspects, is not a new development. Many attempts have been made to use blinded risers to feed members deep in the drag section of molds where it is uneconomical and often impossible to use the open type. These have in general met with rather unpredictable and unreliable success and only recently has a method been developed which makes possible the practical application of the process. Evidences of the basic phenomenon which makes blind risering possible have been so often flaunted in the eyes of foundrymen that it is remarkable that satisfactory methods were not worked out long before 1938. The basic principles, like so many useful developments, are so simple that they were completely overlooked.

8. An interest in and appreciation of the possibilities of successful blind risering developed from conversations between the writers and H. D. Phillips, who was then employed at the Dodge Steel Company. Immediately following this conversation, the writers visited the Dodge Steel Company, where C. S. Roberts and Mr. Phillips illustrated blind risers being used on a practical scale. Subsequent experiments conducted at the Naval Research Laboratory on test castings not only confirmed the claims made for blind risering but indicated the influence of atmospheric pressure in many simple, practical ways.

9. On June 18, 1940, a patent, "Means for Casting Metals*", was issued to John Williams, who, through a keen realization of the advantages to be gained, finally developed a successful method for keeping blind risers open to the atmosphere and made this method of risering a practical foundry tool. To the best of the writers' knowledge, this patent is the earliest publication dealing with the influence of atmospheric pressure on solidifying castings. It is understood that others claim to have realized the theory involved in the process and to have sensed the possible advantages to be gained, but had not found the means of application in the simple form described in the patent. It appears to the authors that this is one of the major recent developments in the foundry industry, not alone because it makes blind risering practical, but because it adds materially to our already fast-growing knowledge of the laws governing solidifying castings, and proves once more how far reaching may be the rewards for digging out answers to the simple foundry problems that are encountered daily.

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* U. S. Patent No. 2,205,327.

GENERAL OUTLINE OF WORK

10. The Naval Research Laboratory undertook to make experimental tests to determine the practical value of the "blind riser" as a method of feeding steel castings and to develop test castings which would show in the clearest possible manner the function of atmospheric pressure in everyday foundry practice. The physical properties of steel castings fed by means of a "blind riser" were compared with castings of the same analysis fed with the conventional open riser.

THEORETICAL CONSIDERATIONS

11. In the transition of molten metal into the solid state, the contractions which occur may be divided into three stages: Liquid, solidification and solid. For steel these are shown diagrammatically in Fig. 1[1]. The portion of the curve *AB* indicates the liquid con-

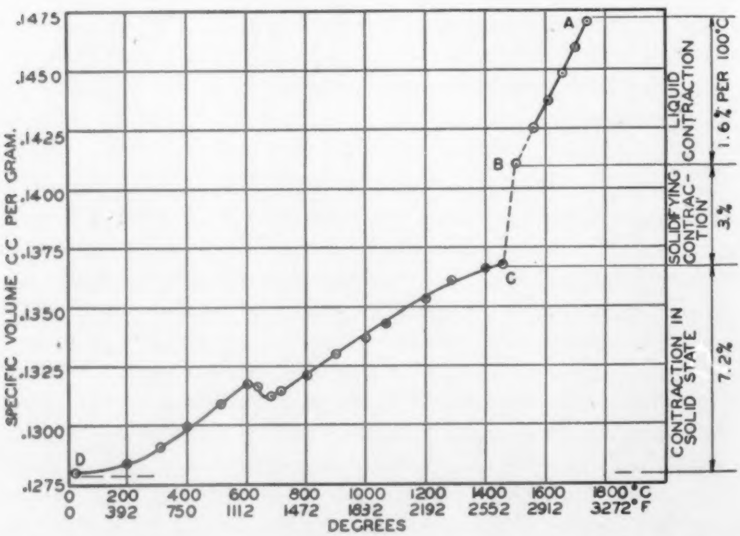


FIG. 1—VOLUME CHANGE RECORDED ON THE COOLING OF A 0.35 PER CENT CARBON STEEL. (BRIGGS AND GEZELIUS.)

traction as 1.6 per cent of the volume for each 100°C. above the

[1] Briggs, C. W., and Gezelius, R. A., "*Studies on Solidification and Contraction in Steel Castings, 11—Free and Hindered Contraction of Cast Carbon Steel,*" TRANSACTIONS, AMERICAN FOUNDRYMEN'S ASSOCIATION, Vol. 43 (1935), pp. 449-476.

solidification temperature. It is this contraction, plus the solidification contraction *BC*, which makes it necessary to use risers as reservoirs of liquid metal to supply the cooling casting.

12. The movement of liquid metal out of the riser and into the casting during this time of diminishing volume is the result of two forces which may either act together or in opposition. The most familiar of these is the force of gravity, or liquid head. The less obvious but even more important force of atmospheric pressure will always be present, tending by one means or another to prevent the formation of any degree of vacuum within the solidifying casting.

13. To illustrate these conditions let us imagine the casting schematically shown in Fig. 2 immediately after pouring, a thin shell of solidified metal and liquid shrinkage having progressed simultaneously upon contact of the metal with the sand. The riser in this case is superimposed upon the casting and designed to be the last to completely solidify due to its greater mass and/or hotter metal. As solidification and contraction progress, the liquid metal in the riser will be acted upon by gravitational and atmospheric forces moving the metal into the casting to prevent the formation of a void. This is an illustration of both forces acting in the same direction.

14. Now consider the casting represented by Fig. 3 in the same condition of partial solidification with the riser at the same level as the top of the casting but placed at one side and again designed to solidify last. As solidification and contraction proceed, atmospheric pressure alone is tending to move the liquid metal from the riser into the casting since gravitational force is balanced out. With atmospheric pressure acting equally on all parts of the casting its direction of effective action will be at that point which offers least resistance. Thus, if no solid shell is allowed to form on the surface of the riser, or if it is weak enough to be ruptured at some point, the force will be at the upper surface of the liquid riser metal and will tend to force the metal downward and then upward into the casting to feed the shrinkage and prevent the cavity which would otherwise form.

15. The cases of additive and individual combinations having been considered, imagine a system where gravity and atmospheric pressure are actually in direct opposition. Fig. 4 is a sketch of a casting being fed by a riser whose height is less than that of the

casting. In other words it is necessary that feed metal be forced to a level higher than the reservoir itself. This system will also be considered in a state of partial solidification with the riser being the last to solidify. It is obvious that in this case the riser cannot reach to the cope surface but must be buried in the mold with the pouring sprue equal to or greater in height than the casting. This is a typical "blind riser" system. Prior to the solidification of the sprue, gravitational forces are similar to those of Fig. 3, but because of the relatively small diameter of the sprue it solidifies long

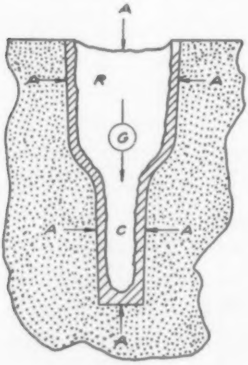


FIG. 2

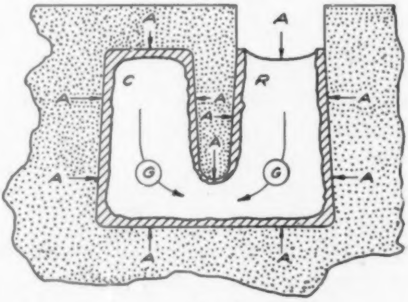


FIG. 3

FIG. 2—CASE 1, GRAVITY AND ATMOSPHERIC PRESSURE ACTING IN THE SAME DIRECTION. LEGEND: A—ATMOSPHERIC PRESSURE; C—CASTING; D—DOWNGATE; G—METAL HEAD OR FORCE DUE TO GRAVITY; R—RISER.

FIG. 3—CASE 2, ATMOSPHERIC PRESSURE ACTING WITHOUT BENEFIT OF GRAVITY TO CAUSE FEEDING. (LEGEND SAME AS FIG. 2.)

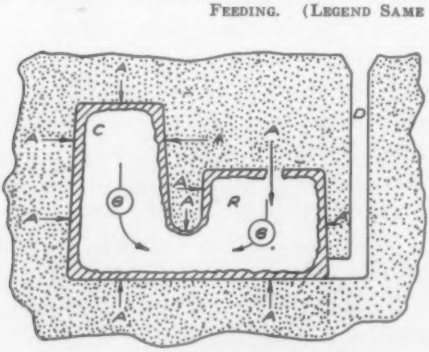


FIG. 4

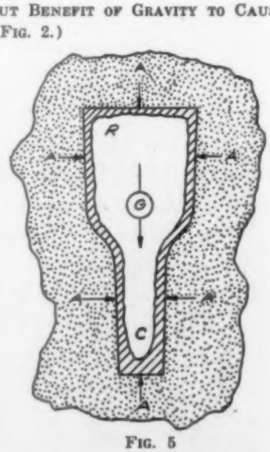


FIG. 5

FIG. 4—CASE 3, METAL HEAD OPPOSITE TO THE DIRECTION OF FEEDING. (LEGEND SAME AS FIG. 2.)

FIG. 5—CASTING AND RISER SOLIDIFYING WITH AN IMPERMEABLE SKIN. (LEGEND SAME AS FIG. 2.)

before the casting and riser and sets up a system in which the liquid head within the casting is actually opposing the desired direction of metal feed. Thus in a completely sealed system, such as would result if a solid skin was allowed to form over the entire surface of casting and riser in such a manner that atmospheric pressure could not gain entrance to the liquid metal, the system would work in reverse and the casting would then tend to feed the riser. However, if the solid shell covering the liquid metal of the riser is kept open at some point during the complete solidification of the casting, a point of entrance is provided for the atmospheric pressure to act on the liquid feed metal. If this force exceeds the gravitational force acting against it, the feed metal will flow from the riser and prevent the formation of shrinkage cavities in the casting.

16. In cases of opposing forces the direction of greatest force, and hence the flow of feed metal, can be determined by the following reasoning. The gravitational force will be directly proportional to the liquid head while atmospheric pressure will be relatively constant at 14.7 lb. per sq. in. For the sake of clarity it is perfectly proper to compare an ideal case of this type of feeding to a simple mercury barometer in which average atmospheric pressure will force mercury to a height of approximately 30-in. Under similar conditions any other liquid is forced to a height which depends inversely upon its density.

17. For molten steel with a density somewhat less than 7.8 the height, calculated from the value for mercury, would be at least 52-in., given by the equation

$$h = 30 \times \frac{13.6}{7.8} = 52$$

Thus, theoretically, it should be possible for a blind riser, when properly kept open and under ideal conditions of solidification throughout the casting-riser system, to force steel upward into a void to a height slightly greater than four feet. This, however, would only be possible if a maximum difference of pressure or, in other words, a perfect void existed in the casting.

18. The examples cited above have covered only those cases in which the liquid metal of the riser was exposed directly to atmospheric pressure at some predetermined point. We must now consider in more detail the case of a solid wall of metal forming over

the entire casting with no artificial means used for providing the atmosphere direct access to the feed metal. The casting sketched in Fig. 5 is a typical example with the skin formation proceeding as shown over the whole casting. Atmospheric pressure will be withstood until shrinkage has formed a partial vacuum within the mold sufficient to provide a difference in pressure between the inside and outside of the casting which exceeds the strength of the solidified shell, when it will either collapse or puncture at its weakest point to relieve the partial vacuum.

19. In the cases above no consideration has been given to the possibility of gas evolution from metal during solidification. This is very probable and the amount of gas which might be evolved would depend upon the state of oxidation of the steel and upon the magnitude of the partial vacuum which formed in the unfed section. In unkilled steel the amount of this gas coming out of solution would tend to keep the partial vacuum low and prevent caving in or puncturing of the walls. Pouring temperature also undoubtedly affects the casting behavior in this respect by influencing both the rate at which strength builds up in the solidifying shell and the amount of liquid shrinkage which governs feed demand.

LABORATORY EXPERIMENTS

20. The experiments which were conducted to test the validity and practical value of the above reasoning will now be discussed.

Case 1—Additive Forces

21. The casting of Fig. 6 shows the most simple form of open riser possible where the riser is superimposed directly above the section to be fed. The force of gravity or metal head is acting in the same direction as the force due to atmospheric pressure and feeding naturally follows well known rules. Immediately after casting, the riser was covered with ripe eliminator to insure maximum feeding and to provide the atmosphere ready access to the liquid feed metal. This casting and all others of the same type shown were gated into the middle at the parting line.

Case 2—Individual Action

22. Figs. 7A and 7B show the side and top views respectively of a system of two typical blind risers of equal size and shape, gated similarly, and identical in every respect except that one was kept

open to the atmosphere by means of a sand core, and the other was not. The riser which was not kept open may be thought of as the casting. This method of gating is used on all casting systems unless indicated otherwise. It would seem that these risers should solidify at the same rate and shrinkage occur independently and yet the riser which has been kept open has very nearly completely fed the other. It is clear that although the force of gravity is initially equalized with the same metal head in each riser, atmospheric pressure alone has been sufficient to overcome the balance and accomplish feeding. It is not at all surprising that the casting is not completely solid since no attempt was made to influence the thermal gradients to favor either casting or riser. The surprising thing is

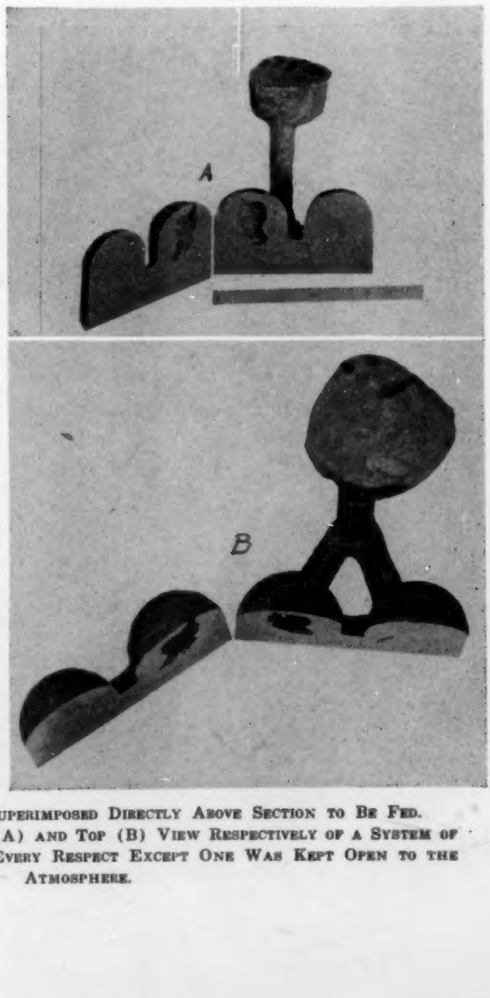


FIG. 6—(LEFT) OPEN RISER SUPERIMPOSED DIRECTLY ABOVE SECTION TO BE FED.
FIGS. 7A AND 7B—(RIGHT)—SIDE (A) AND TOP (B) VIEW RESPECTIVELY OF A SYSTEM OF TWO BLIND RISERS IDENTICAL IN EVERY RESPECT EXCEPT ONE WAS KEPT OPEN TO THE ATMOSPHERE.

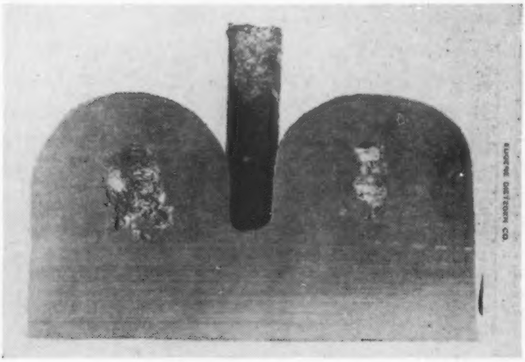


FIG. 8—SYSTEM IN WHICH CASTING AND RISER ARE IDENTICAL AND NEITHER KEPT OPEN TO THE ATMOSPHERE.

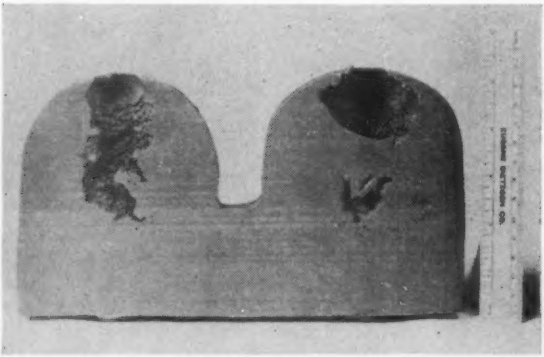


FIG. 9—SYSTEM IN WHICH CASTING AND RISER ARE IDENTICAL AND BOTH OPEN TO THE ATMOSPHERE.

FIG. 10—RISER SAME HEIGHT AS CASTING BUT OF GREATER MASS.

that the final cavity in the casting was not a great deal larger.

23. Fig. 8 is a similar system in which neither riser nor casting was kept open to the atmosphere and, since the effect of gravity was balanced out, shrinkage occurred in each with no tendency of one to feed the other. Fig. 9 shows an analogous system in which both riser and casting were kept open. Fig. 10 shows a case where the riser is the same height as the casting, each being five inches, but the riser is 5 in. in diameter and the casting is 4. Thermal gradients are thus favorably disposed toward the riser because of its greater mass and it accordingly solidifies last. Since it was kept open to the atmosphere complete feeding has resulted, and the metal of the casting is solid.

Case 3—Opposing Forces

24. Fig. 11 illustrates the condition in which the gravitational force of the section being fed actually opposes the atmospheric pressure exerted upon the liquid metal in the riser. Figs. 24 and 25 are detailed sketches of the system. In Fig. 11 the casting is 10 in. and the riser only 6 in. high but feeding has been entirely adequate. In all cases solidification must be so controlled that the riser and the neck into the casting solidify last. This system will be discussed in greater detail below.

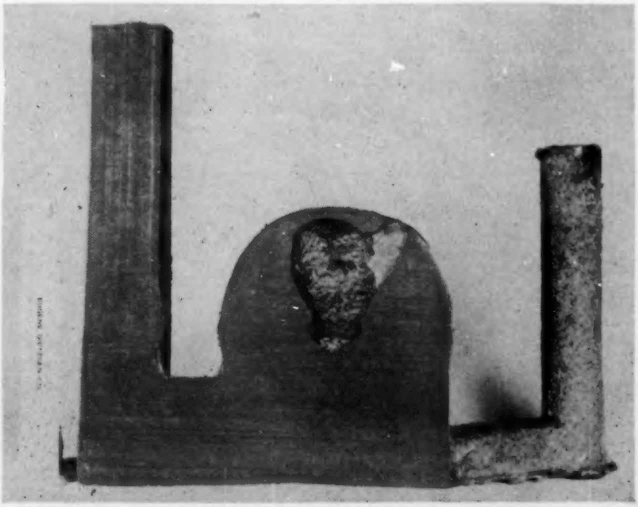


FIG. 11—SECTION OF AN EXPERIMENTAL CASTING IN WHICH GRAVITATIONAL FORCE OPPOSES FEEDING.

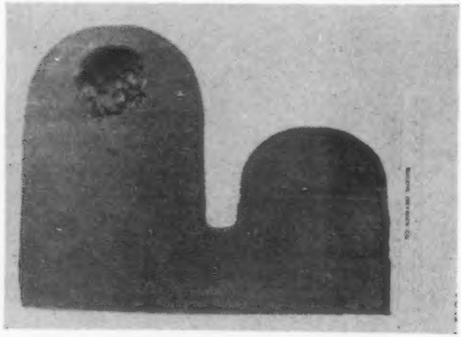


FIG. 12—CLOSED SYSTEM IN WHICH GRAVITATIONAL FORCE IS ACTING ALONE.

FIG. 13

FIG. 14

FIG. 13—COLLAPSED WALLS RESULTING FROM INTERNAL SHRINKAGE AND EXTERNAL ATMOSPHERIC PRESSURE.

FIG. 14—SAME CASTING AS FIG. 13 EXCEPT RISER WAS KEPT OPEN TO THE ATMOSPHERE.

25. For an illustration of the relative influences of gravitational forces acting independently of atmospheric pressure and vice versa, Figs. 10 and 12 provide a striking comparison. The former illustrates atmospheric pressure as the prime mover of the feed metal and the latter showing gravitational force acting alone. In the system of Fig. 12 neither blind head was open to the atmosphere, but it might be expected that the greater metal head in the larger riser would be sufficient to accomplish the necessary feeding. Besides being higher, this riser was also 5 in. in diameter as compared to 4 in. for the section being fed. A casual glance at the photograph might indicate satisfactory feeding but considerable sponginess was found in the casting. Thus, atmospheric pressure has accomplished adequate feeding of a given section under conditions where a much larger reservoir failed when gravitational force was acting alone. It has been mentioned that the casting of Fig. 10 was sound.

26. As a practical demonstration that atmospheric pressure causes caving in of the walls of a casting in unfed or incompletely fed sections the castings shown in Figs. 13 and 14 were made. The collapsed walls of the casting shown in Fig. 13 are the combined result of internal shrinkage and the external action of atmospheric pressure. The wall of solid metal formed at the sand-metal interface is at a very high temperature and correspondingly weak and plastic for some time after solidification begins. In a properly fed section the force outward is kept equal to or greater than the value of atmospheric pressure and the casting solidifies with flat walls. However, if this is not the case, shrinkage will create a partial vacuum within the section, the force outward against the wall will decrease, and if the strength of the solid skin is still below a value which will resist it, the walls will be caved in by atmospheric pressure alone. The truth of this statement is borne out by the fact that the castings shown were made in bentonite bonded dried sand molds of very high permeability, ruling out gas pressures very much in excess of atmospheric pressure. This illustrates the condition where no puncture formed to allow the atmosphere to reach the liquid metal. Fig. 14 shows a similar casting purposely kept open to the atmosphere. No partial vacuum was allowed to form and there was no tendency for the walls to collapse. It will be remembered that the casting of Fig. 6 also solidified with straight walls. If pronounced hot spots or weak points exist in an otherwise continuously solidifying shell, it may puncture rather than col-

lapse without any artificial means being provided. This is discussed below.

27. In making laboratory test castings, 36 in. high with a 9 in. high blind head, the walls persistently collapsed in the top 6 in. To overcome this a larger downgate and sprue system was used which remained liquid and kept the internal pressure against the casting walls greater than atmospheric throughout the system, until the shell of metal formed was strong enough to resist deformation. This height was nearing the limit to which atmospheric pressure can force metal upward and the blind head did not supply the early feed demand unassisted but was, however, able to accomplish necessary feeding by the time the enlarged sprue system solidified.

28. In instances when shrinkage is compensated for externally, the walls of the casting will be sound, and occasionally in thinner members the whole section will be solid. The latter is an example of internal shrinkage being completely accounted for by external shrinkage. Atmospheric pressure sometimes acts in another way even more detrimental to the internal integrity of the casting. The large number of blowholes and cavities which occur in the region of congested areas of sand, such as internal angles, can also be laid directly to the same combination of influences that cause the walls of castings to collapse. Fig. 15 shows a photograph of a typical defect of this kind. The exaggerated shrinkage seen in the left leg of the keel block is the result of atmospheric pressure acting in a manner analogous to a blind head with the sharp wedge of sand creating the necessary hot spot.

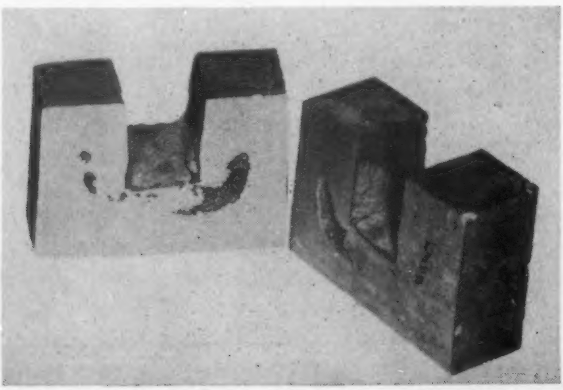


FIG. 15—ATMOSPHERIC PRESSURE BREAKING THROUGH THE SOLIDIFIED SHELL AT A HOT SPOT.

29. The shrinkage which would normally have been equalized between each leg is decreased in the right because it was partially fed from the left. The manner in which this takes place is thought to be as follows: Since feeding was purposely inadequate, shrink-

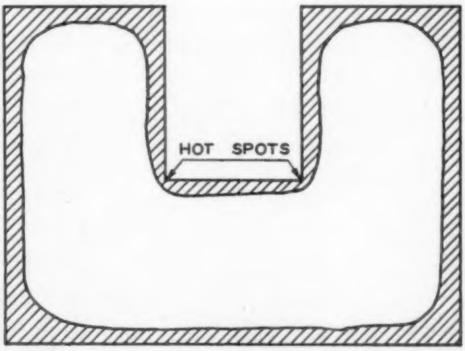


FIG. 16—SKETCH SHOWING RELATIVE RATES OF SKIN FORMATION AT INTERNAL AND EXTERNAL ANGLES.

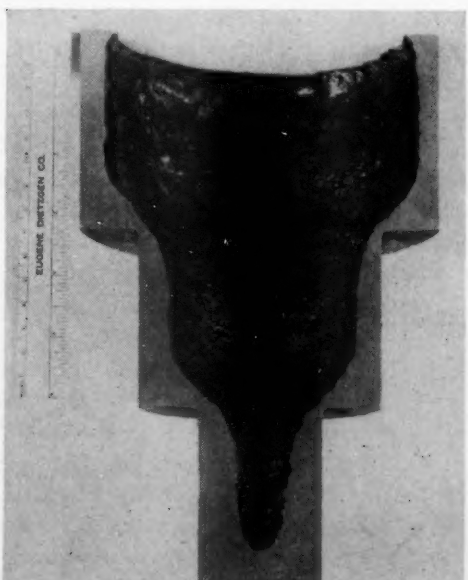


FIG. 17—CASTING SHOWING RELATIVE RATES OF SKIN FORMATION AT INTERNAL AND EXTERNAL ANGLES.

age occurred in the casting. The skin of solidified metal which forms at the sand-metal interface thickens at a rate which is dependent upon the cooling surface. Naturally the areas of sand on the open faces of the casting conduct heat away rapidly with a maximum rate of solidification as shown in Fig. 16. The sand in the internal angles cannot conduct heat away rapidly, hot spots exist in the casting at these points and the skin formed is relatively thin and weak.

30. The photograph of Fig. 17, taken from work at this laboratory by Briggs and Gezelius, shows more clearly perhaps the relative trends of skin formation on internal and external angles. This particular casting was made in a vertical position and poured through the large end which was uppermost. After one minute the mold was inverted and the casting bled. In a similar mold, at the end of five seconds, the average wall thickness on the outer surfaces was 3/16 in. while at the internal angles the wall was paper thin and the sections broke apart at this point. Whenever such a condition exists it is quite often in the region of a heavy section and with shrinkage tending to form a partial vacuum within the casting, the atmospheric pressure acts to rupture the wall at its weakest point and forces a hole into the casting at the hot spot to relieve the partial vacuum inside. Fig. 15 is a typical example of this type of defect which is not uncommon in steel castings.

31. One foundryman describes similar defects as being caused by a "Leonard Effect" which is explained as "— gases escaping from a congested part of sand, strongly heated by metal and not sufficiently permeable to allow the amount of gases produced to escape to the exterior of the mold." The writer goes on to say that, "In many cases a waster had been brought to the author for advice in which holes had been the result of 'Leonard Effect', while the questioner thought it was either wrong metal, or shrinkage cavities, or something else." The writer also stresses the point that this "Leonard Effect" should not be confused with real shrinkage cavities.

32. The peculiar feature of this defect is that it is apt to occur in dried sand molds and in sands of high permeability, and it normally depends upon real shrinkage for its initiation. If the cause is as simple as the formation of excessive gas pressures, the provision of highly permeable sand should solve the problem. There is no doubt that excess gas pressures and lack of permeability are contributing causes in many cases, but that they are not entirely

responsible is shown in a rather striking manner by Figs. 18, 19 and 20. The casting of Fig. 18 is a round bar into which a thermocouple was cast. This bar was used as a temperature control for a duplicate bar poured simultaneously and identical in every respect except for the absence of a thermocouple. The sketch of Fig. 18 shows how the mold was assembled. The thermocouple wires were platinum and were protected by a two-hole alundum sheath which was open at each end. After pouring the castings, discrepancies in the temperatures recorded often indicated something amiss and upon sectioning such castings a cavity was always found. In some cases the temperature would be as expected and in these cases sound metal was found around the thermocouple bead. The variation in results from time to time indicated something unusual and for a while it was thought that oil or other gas-forming substance might be present which would expand at the high temperatures involved and create the excessively large cavities. In spite of utmost care exercised in keeping the tips clean the cavities persisted in recurring. The phenomenon causing this unusual condition was evidently somewhat out of the ordinary.

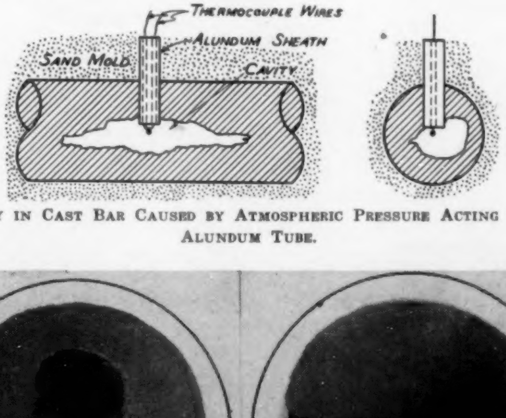


FIG. 18—CAVITY IN CAST BAR CAUSED BY ATMOSPHERIC PRESSURE ACTING THROUGH THE ALUNDUM TUBE.

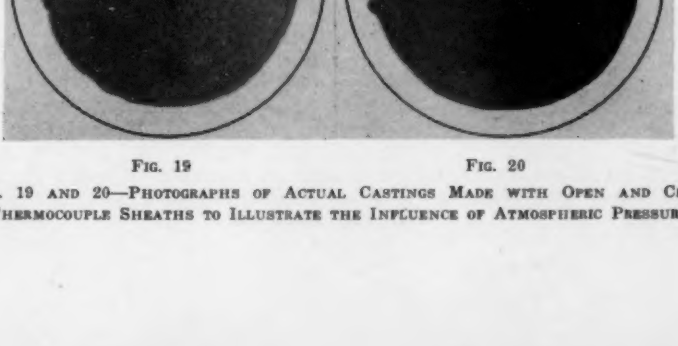


FIG. 19 FIG. 20

FIGS. 19 AND 20—PHOTOGRAPHS OF ACTUAL CASTINGS MADE WITH OPEN AND CLOSED THERMOCOUPLE SHEATHS TO ILLUSTRATE THE INFLUENCE OF ATMOSPHERIC PRESSURE.

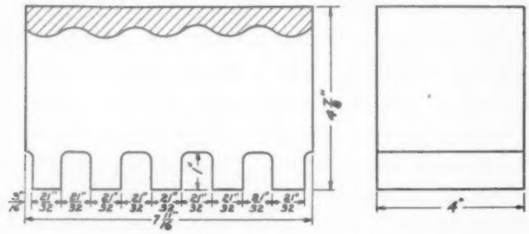


FIG. 21—TEST COUPON MADE WITH OPEN RISER.

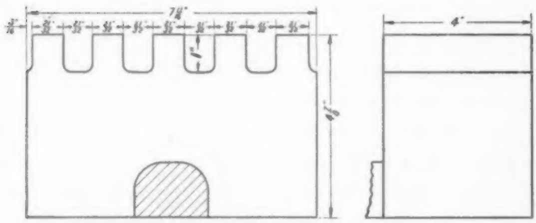


FIG. 22—TEST COUPON MADE WITH BLIND RISER.

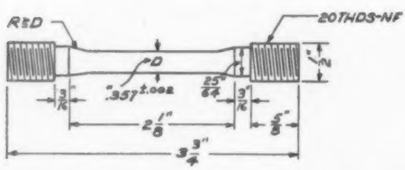
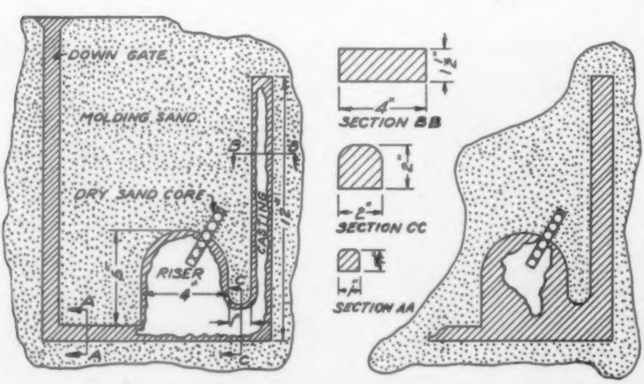


FIG. 23—DETAILS OF TENSILE TEST SPECIMEN.



FIGS. 24 AND 25—SCHEMATIC DRAWINGS OF MOLD AND CASTING TO ILLUSTRATE THE PRINCIPLES OF BLIND HEAD FEEDING. (FIG. 24 LEFT) PARTLY SOLIDIFIED, AND (FIG. 25 RIGHT) COMPLETELY SOLIDIFIED.

33. After studying all other possible causes it was decided that perhaps atmospheric pressure was being transmitted through the holes of the alundum sheath into the center or liquid part of the bar where a shrinkage cavity was tending to develop. The atmospheric pressure localized the shrinkage into one large cavity. The obvious remedy was to use a closed sheath to prevent this easy admittance of air, and when this was done solid castings were always obtained. Figs. 19 and 20 show a cross-section of castings made with the open and closed sheath, respectively.

34. In several experimental castings where defects were initiated at hot spots, it was necessary to examine the casting microscopically in order to detect the small opening from the cavity to the outside of the casting, but with enough care one was always found.

35. The physical properties of castings are the same whether made with open or blind risers if each is properly applied. The results shown in Table 1 tend to bear out this statement as do the many tons of radiographically sound and pressure tight castings made daily by each method. The tensile test specimens are given in Fig. 23. The "A" specimens were cut from the bottom of the gravity fed coupon of Fig. 21 and the "B" specimens from the top of the coupon fed with a blind head (Fig. 22). As might be predicted, the additional "ferro-static" or gravity head has not produced castings with better mechanical properties than those fed with atmospheric pressure alone.

36. Figs. 24 and 25 represent schematically a layout for the use of a blind head for feeding the heavy section of a casting. In attempting to clarify the nomenclature, it is suggested that definite terms be adopted in referring to a blind head feeding assembly.

Table 1

COMPARISON OF THE PHYSICAL PROPERTIES OF STEEL CASTINGS* FED BY MEANS OF OPEN AND BLIND RISERS

Specimen	*Yield Strength lb. per sq. in.*	*Tensile Strength lb. per sq. in.*	*Elongation in 1½ in. Per Cent*	*Reduction of Area Per Cent*
A1	63,800	78,400	30.2	65.4
A2	63,300	77,000	30.2	66.3
Ave.	63,550	77,700	30.2	65.9
B1	64,000	77,600	30.2	68.0
B2	63,200	76,600	32.2	68.0
Ave.	63,600	77,100	31.2	68.0

* Chemical Analysis (Per Cent)—*C.*, 0.13; *Mn.*, 0.70; *Si.*, 0.95; *Cu.*, 1.69; *S.*, 0.03; *P.*, 0.03.—Specimens dead annealed.

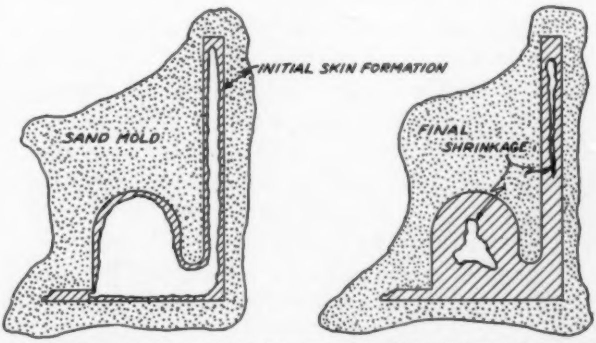
In this paper the channel "AA" leading from the downgate to the head will be the "ingate" and "CC" leading thence into the casting will be referred to as the "neck." This follows the terminology of most shops familiar with blind head feeding.

37. The sketch shows the casting actually 5 in. higher than the top of the blind head. In the manufacture of average commercial castings, such as valves, for which the blind head is especially suited, this situation seldom exists. In general the mass of the flange or other section is great enough to require a blind head very nearly as high as or slightly higher than the part it is to feed, especially since the bottom of the riser is placed at or slightly below the parting line. In these examples, as in blind risering in general, the metal poured into the ingate must flow first through the riser and then into the casting.

38. As soon as the mold is completely filled, the metal loses temperature rapidly to the sand and a skin of solid metal quickly forms at the mold-metal interface. This initial skin formation is shown as the cross-hatched areas of the figure. As temperature continues to drop, more and more metal solidifies and the liquid shrinkage accompanying the falling temperature tends to form the partial vacuum within the solidifying mass. The skin forming on all parts of the casting is impermeable except at the desired spot on the riser. In this case as solidification continues in the casting proper, the atmospheric pressure plus any gas pressure in excess of this value acts like a piston on the metal in the blind riser, forcing it into the casting to feed shrinkage. In other words the system is functioning like a mercury barometer. Shrinkage is constantly tending to create the necessary partial vacuum in the casting and atmospheric pressure, acting through the medium of the molten metal in the riser, is constantly relieving it. If solidification proceeds properly, with the parts most remote from the riser freezing first and progressing thence toward the riser, each successive amount of shrinkage is compensated by additional fluid metal forced in from the riser. The ingate, being small, freezes off first and completes this part of the closed system. Figs. 26 and 27 show a similar system in which a completely impermeable skin forms, and shrinkage takes place independently in casting and riser with the resulting cavities.

39. Figs. 28, 29 and 30 show examples of keel-block castings made with a blind head. Fig. 28 shows the manner of casting and

Figs. 29 and 30 show the castings sectioned. In one case the riser is kept open to the atmosphere and in the other it is not. In Fig. 29 solidification has taken place independently in the casting and in the riser, while in Fig. 30 the total shrinkage is accounted for in the riser alone. As many as 5 such castings have been made from a single blind head. It is only necessary that the volume of metal in the blind head be greater than that necessary to compensate for



FIGS. 26 AND 27—SCHEMATIC DIAGRAM ILLUSTRATING (FIG. 26 LEFT) INITIAL SKIN FORMATION AND (FIG. 27 RIGHT) FINAL SHRINKAGE IN A CASTING UNSATISFACTORILY FED BECAUSE THE BLIND HEAD WAS NOT KEPT OPEN TO THE ATMOSPHERE.

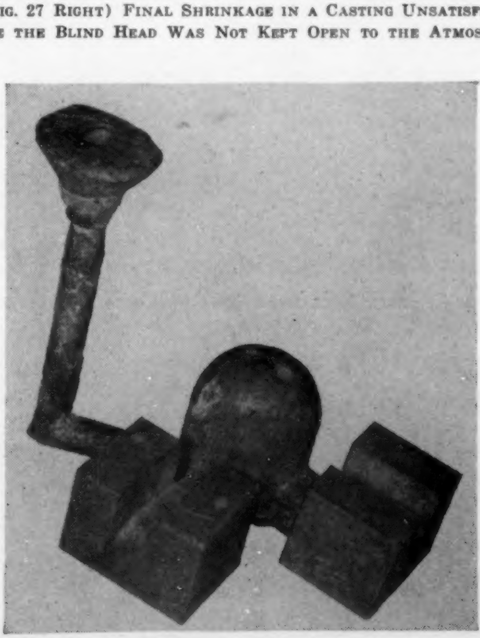


FIG. 28—METHOD OF MAKING KEEL BLOCK CASTING WITH A BLIND RISER.

the liquid shrinkage of the system before final freezing of the riser.

40. Figs. 31 and 32 show the top and side view of a typical method of feeding a valve flange with a blind riser. The sketch is largely self-explanatory.

41. Several means can be used for keeping a blind head open. As a matter of fact in cases where very hot metal is used and an early feed demand develops in the casting the riser may break through without any artificial means being provided. However, this is far too uncertain to depend upon. A sharp wedge of sand may be molded into the top part of the riser and in many cases this method is satisfactory. The sharp edge of the wedge of sand sticking down into the metal furnishes the necessary hot spot but as in the case above cold metal and late feed demand may often combine to cause this method to be ineffective. The use of thermit either made up as a core or held in readily melted metal tubes placed at the top of the riser has been found satisfactory by some foundrymen and actually increases the efficiency of blind risers by the

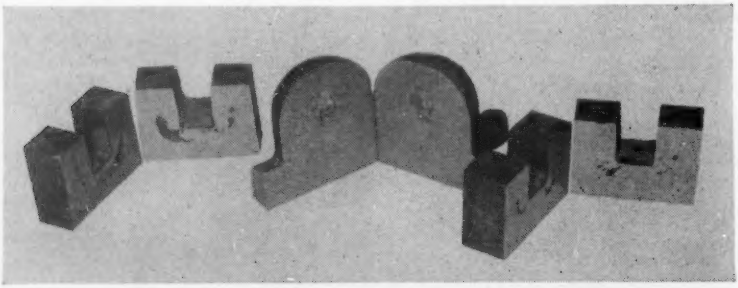


FIG. 29—KEEL BLOCK WITH RISER CLOSED TO ATMOSPHERE.

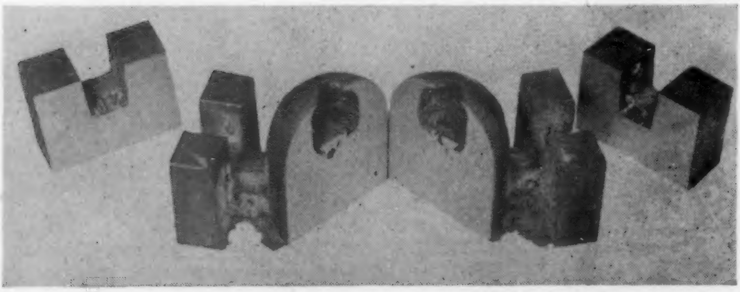


FIG. 30—KEEL BLOCK CASTING WITH RISER OPEN TO ATMOSPHERE.

exothermic addition of heat. The material is expensive, however, and this method will probably not become popular for that reason. These methods have all been tried at the Naval Research Laboratory with the results reported above and none appeared to function with the same degree of certainty and simplicity as the dried sand core. The method developed by the Dodge Steel Company consists of imbedding a round dried sand core in the sand at the top of the blind riser so that it extends into it for a distance roughly equal to the radius of the riser in the manner shown in Fig. 32. This is a simple rod core of a type found in the average foundry except that a small vent hole extends through the center. This vent hole is not absolutely necessary but is recommended. The only

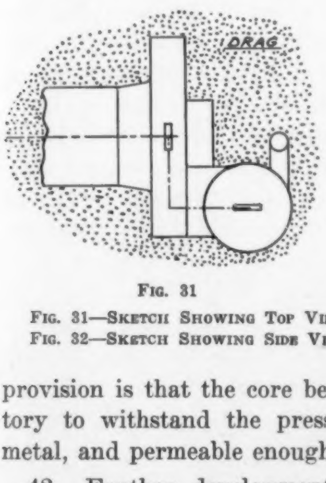


FIG. 31

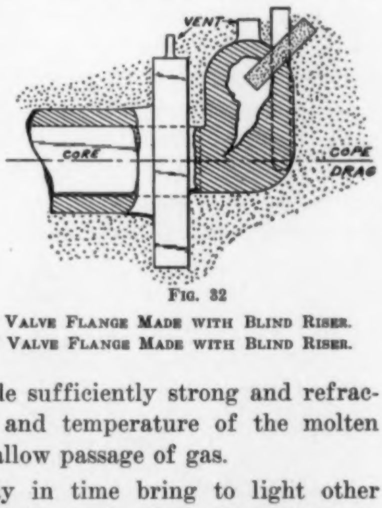


FIG. 32

FIG. 31—SKETCH SHOWING TOP VIEW OF VALVE FLANGE MADE WITH BLIND RISER.
FIG. 32—SKETCH SHOWING SIDE VIEW OF VALVE FLANGE MADE WITH BLIND RISER.

provision is that the core be made sufficiently strong and refractory to withstand the pressure and temperature of the molten metal, and permeable enough to allow passage of gas.

42. Further development may in time bring to light other methods even more useful for certain applications. Several methods have been tried but have proved either more complicated or more expensive than the simple core. In action the core breaks the seal which would otherwise form completely over the riser by extending into the center where there is still liquid metal. Thus atmospheric pressure, acting through the permeable core, is able to force the metal from the riser into the partial vacuum tending to form within the casting proper. The sand of the mold is sufficiently permeable to allow an easy passage of gas to and from the core so that the full benefit of atmospheric pressure is realized. It has not yet been definitely determined whether the gas generated instantaneously by the core is necessary to initiate the contact with the atmosphere but it is added assurance.

43. After understanding the principles behind blind risering it is readily apparent that sand cores can be used to advantage in open risers to prevent secondary shrinkage. By securing them in the sand at various levels with one end protruding into the center of the open riser, they prevent the possibility of the riser cutting off atmospheric contact by freezing over.

FOUNDRY CONSIDERATIONS IN THE USE OF THE "BLIND RISER"

44. For many castings considerable advantages in economy and convenience are possible through blind riser feeding, but naturally whether to use it or the alternate and more common method of feeding with open risers should be decided on the basis of casting design. No fixed rules can be given at present regarding when blind heads are to be preferred to open types, but with a few basic facts and a progressive attitude the average foundryman can determine his practice from a relatively short experience with the method. In general it may be said that blind riser feeding has found its greatest application in the light and medium light casting fields; that is, in castings weighing less than a ton. Some of the advantages and disadvantages of the method follow in detail.

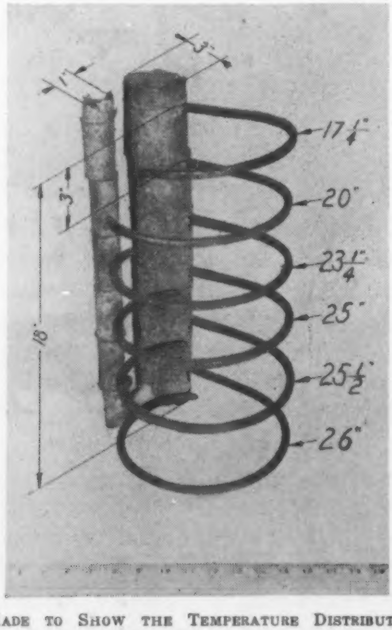


FIG. 33—CASTING MADE TO SHOW THE TEMPERATURE DISTRIBUTION RESULTING FROM BOTTOM POURING.

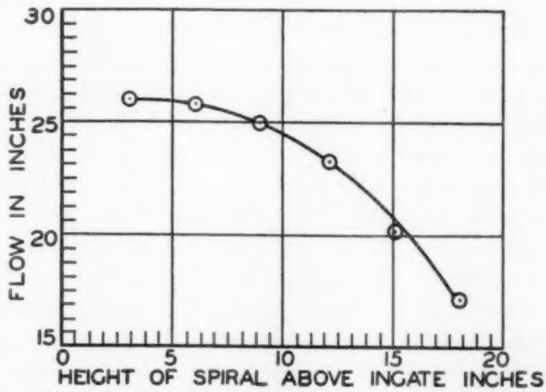


FIG. 34—CURVE SHOWING TEMPERATURE DISTRIBUTION IN THE BOTTOM POURED CASTING OF FIG. 33.

Advantages

45. *A. Hotter feed metal:* In being able to gate through the blind riser into the casting proper the foundryman enjoys a distinct advantage. The sand around the riser is preheated to a high temperature and when pouring is finished the last metal to enter, and hence the hottest, is in the riser where it should be. Likewise metal in the parts of the casting farthest from the riser is coldest by virtue of being the first to enter and having lost heat continually to the sand in passage. Thermal gradients are thus favorably disposed with the riser being the last to solidify. Proper directional solidification is vitally necessary and is generally more easily attained by gating into risers, a simpler procedure with blind risers than with open risers.

46. *B. Bottom gating is fully practical:* Bottom gating is preferred whether blind or open risers are used because there is less erosion of sand surfaces and the metal is generally cleaner. While bottom gating through blind risers is an advantage in all respects, it is many times a source of trouble with open risers. In the latter case the metal for feeding the solidifying casting must come from the top and should be the hottest, but in bottom pouring castings made with open risers this situation is reversed with the colder metal at the top having to do the feeding. This is responsible for a good many defective castings, the blame for which is often laid elsewhere.

47. The photograph of Fig. 33 shows how temperatures can vary between the upper and lower sections of even small bottom-poured castings. The illustration is largely self-explanatory. The

mold was made up of seven sections of core sand with spiral flow channels tapped off from the header at three-inch intervals. The spirals serve to measure the fluidity or flowability of the steel at the various levels, and since this quantity has been shown in a previous Naval Research Laboratory publication[2] to be a direct function of temperature for a given analysis of steel, the length of flow affords a relative indication of the temperature. Fig. 34 records the spiral lengths graphically as a function of their positions above the ingate and shows in a practical way the tendency of the steel to cool rapidly in rising upward. The time of pouring and height of the test casting are both small compared to large bottom poured castings so it can be readily seen that by the time many bottom poured molds are completely filled the metal in the riser is nearly ready to solidify.

48. *C. Generally cleaner castings:* Experience at those plants in which the blind head is used regularly and at this laboratory indicates that, with good sand practice and proper care, actually fewer bad castings result from dirty molds than when open risers are used because open risers are a potential source of trouble from foreign matter falling into the mold. With molds employing blind risers this danger is eliminated except for the relatively small ingate. By gating tangentially into the blind risers a swirling action is set up which causes them to act as skim gates. This prevents sand and dross from entering the mold through the sprue system.

49. *D. Saving in cleaning cost*: The most pronounced difference between open and blind risering is in the position of the risers with respect to the sections they feed. The area of contact between the riser and the casting is considerably reduced and more favorably placed in the blind riser and this represents a very real economy in cleaning cost and an improvement of the general appearance of the rough casting after the risers are removed. The blind riser can be placed on flat surfaces and in positions easily accessible to torch and grinder. When open risers are used in the manufacture of valve castings heavy padding of the flanges has been found necessary. This padding, shown in Fig. 35, besides adding materially to the mass of the casting, is inconvenient to remove. Figs. 32 and 35 afford a comparison between the two methods.

50. *E. Increased yield through more economical feeding*: The shape of the blind riser is advantageous from the design stand-

[2] Taylor, H., Rominski, E., and Briggs, C. W., "*The Fluidity of Ingot Iron and Carbon and Alloy Cast Steel,*" TRANSACTIONS, AMERICAN FOUNDRYMEN'S ASSOCIATION, Vol. 49 (1941), pp. 1-93.

point. The ratio of surface area to volume is considerably less for round feeders than for those of any other shape and, since the rate of solidification is directly proportional to this ratio, the spherical shape of the blind riser as compared to the more usual square or rectangular shape of open risers makes it possible to use smaller heads and effect an increase in casting yield. This increase in yield may or may not be realized depending upon the type of work being made and the existing method of manufacture. For a comparison, however, it is safe to predict that if sound castings of types suitable for either method of risering are already being made with open risers and the foundryman proceeds to make them equally sound by the most economical application of blind risers, a definite increase in yield will result. By being able to gate into the risers this part of the mold is preheated and the hottest metal left for feeding. This automatically disposes temperature gradients toward the risers without the necessity for making them excessively large. It is clear that in those instances where the risers must extend through the cope for a distance in excess of that needed to supply the necessary height of riser to properly feed the casting, a saving will result from the use of the blind type. This is particularly true when it is necessary to feed sections at the bottom or near the center of large castings.

51. *F. More solid castings through a better understanding of the risering process:* By being able to place blind risers at any point inside the mold the foundryman has considerably greater feeding possibilities. Hidden sections, bosses, and parts of the casting deep in the drag can be adequately fed without excessive chilling or the use of oversize open risers extending all the way through the cope. The old excuse for unfed sections being "beyond the feeding range" is now more of a myth than ever before. It is believed that a complete understanding of the principles involved in blind risering leads directly to a better understanding of risering in general and of the mechanism of solidification.

52. It has been stated by persons using the process that since putting it into regular practice they have found it a good deal easier to standardize their gating and risering routine and that in many cases the decrease in height of cope required has been of substantial advantage.

Disadvantages

53. *A. Larger flask size often needed:* By placing the blind

risers to the side of the sections they are to feed rather than above them, as in the case of open risers, a larger flask size is necessary for making a given job. However, this is not a very serious matter and may be offset by the decreased height of cope.

54. *B. May trap dirt or dross:* A possible disadvantage in the use of blind risers lies in the possibility of trapping dirt and dross in the main body of the casting if no open riser is present into which it can collect. Only such foreign matter as is already in the casting part of the mold will be harmful, however, as any which originates in the pouring basin, sprue, or ingate will be kept in the blind head by the swirling action of the metal. Good sand practice and care in closing molds obviates this disadvantage.

55. *C. Patent:* The simple means used by the authors for keeping blind heads open to the atmosphere with sand cores is patented.

DISCUSSION OF PRACTICAL FEATURES

56. Since blind head feeding is a relatively new process, a rather detailed discussion of the practical features involved will be offered in the light of present knowledge. Some of the immediate problems confronting the foundryman are: (1) the choice of the proper and most economical size and shape of head to use, (2) size and shape of neck between riser and casting, and (3) the position of the blind head relative to the section it is to feed.

(1) Size and Shape of Blind Head

57. Because the amount of liquid shrinkage in any particular casting depends on the temperature of the metal used, no hard and fast rule can be laid down which will solve the problem of feeder size for a given section. Variations normally exist in commercial practice between the temperature of the first and last molds poured from a single ladle, and shrinkages are higher in those shops pouring on the hot side. The differences in cooling rates which depend on the material of the mold, casting contour, and composition of the steel must also be taken into account. Here again it is necessary to draw heavily upon individual experience but in general judgment is developed after a very short experience with the method. In many cases it is possible to operate on the heavy and safer side and still attain advantages over the open riser so a reasonable time can be allowed to gain experience without the sacrifice of castings or economy.

58. By purposely designing oversize and sectioning the feed

head with torch or saw it is possible to arrive at a useful approximation of the volume of feed head needed for a particular section without sacrificing castings and time for experimentation. It is desirable that the final shrinkage cavity in the riser should extend to, but not below, the upper level of the neck leading to the casting. This provides a reasonable though not excessive factor of safety against running the cavity into the casting proper and will usually provide for normal variations in the temperature of the metal used for casting.

59. Some of the pictures of actual patterns included in this paper give an idea of the size and number of blind heads required for a particular job. The ruler is one foot long and by scaling off the various sections a good approximation of relative sizes can be obtained. If one could estimate the volume of section to be fed, the volume of the blind head required to satisfactorily feed it would seldom be more than 10 per cent in excess of this amount. Fig. 7*a* showed the one blind head which was kept open almost completely feeding another of the same size which was not. The shape of blind heads for maximum feeding should be that of a hemisphere superimposed upon a cylinder with the overall height above the bottom of the ingate into the casting at least one inch greater than the diameter.

(2) Dimensions of Neck and Ingate

60. Fig. 24 indicates the neck into the casting as of a square cross-section with the upper edges rounded. An approximate 2 to 1 ratio of neck size to the thickness of the section to be fed holds well for small valve flanges and similar shapes but must be modified in proportion to feed larger sections. Naturally, the only requirement is that it shall not freeze off prematurely, and this is influenced not only by its size and shape but by the amount of metal flowed through in filling the casting. This ratio would decrease inversely with section thickness, but the neck *will never be smaller* than the section to which it is attached.

61. In Figs. 7A and 7B the neck was much smaller than the largest section and feeding was possible because the neck solidified slowly due to the narrowness of the section of sand between the riser and the body of the casting. Heat loss through this section is very slow and generally the sand around the neck is preheated by metal flowing through this channel to fill the casting. However, in these tests a runner was connected directly to each blind head

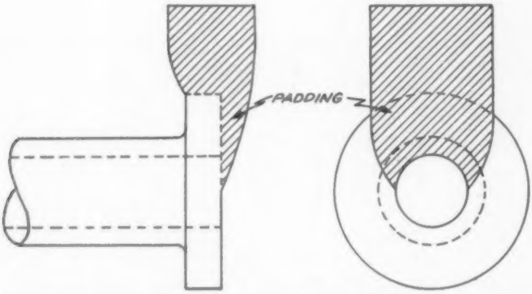


FIG. 35—SKETCH OF VALVE FLANGE MADE WITH AN OPEN RISER.

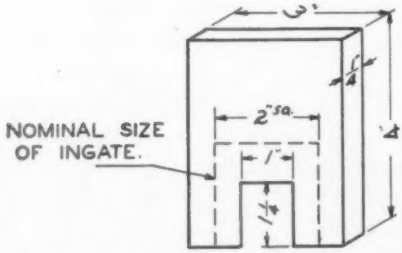


FIG. 36—DETAILS OF THE CORE USED FOR REDUCING THE SIZE OF NECK INTO THE CASTING.

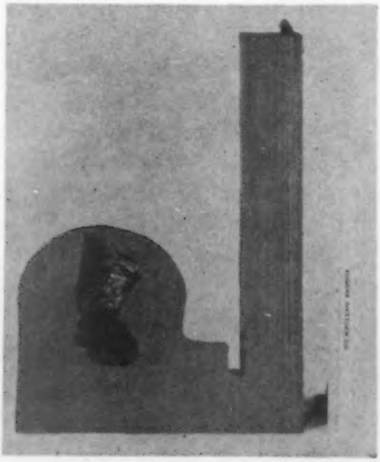


FIG. 37—CASTING MADE WITH A CHOKE CORE AT THE NECK.

and yet the neck remained open nearly long enough to complete feeding. The hot metal continuously being forced into the section to be fed undoubtedly retarded the solidification of the neck.

62. In attempting to make removal of the feed head as simple as possible the principle of the Washburn core was applied to one test casting. A strong linseed oil plate core 1/4-in. thick was made with a rectangular section 1-in. x 1 1/4-in. cut from one side as in Fig. 36. This was placed in the mold across the neck in position to give the effect shown in Fig. 37. The purpose was to see if the blind head would feed properly through this necked down portion. If this was possible the removal of blind risers would be greatly simplified. The original cross-section area of the ingate was approximately 4 sq. in., as compared to 1 1/4 sq. in. at the choke. The photograph of the casting indicates that the method will work satisfactorily, but too few tests have been made to establish this as

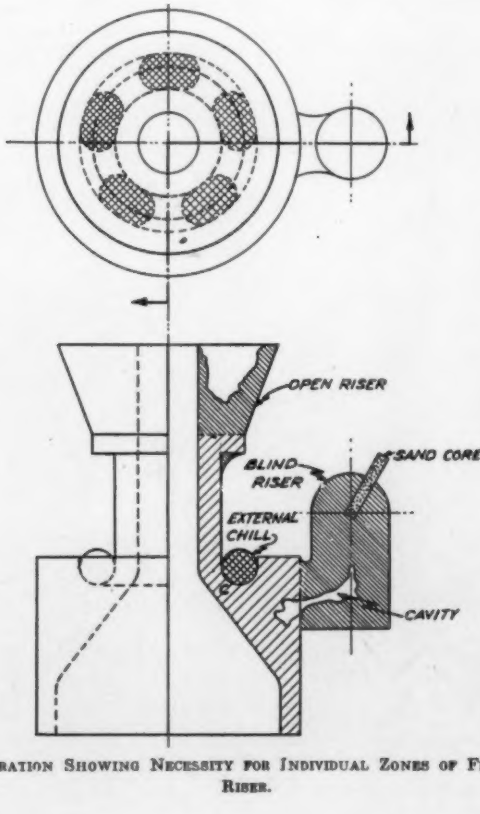


FIG. 38—ILLUSTRATION SHOWING NECESSITY FOR INDIVIDUAL ZONES OF FEEDING FOR EACH RISER.

a reliable practice. The success of the method depends upon the core being thin enough to heat up readily to the temperature of the metal flowing through. This prevents premature chilling of the section. In using the choke it should be placed at least one-fourth inch from the casting to prevent gouging into it during removal of the risers. Also the amount of choke must be carefully regulated.

63. The size of ingate varies but should be considerably smaller than the neck. This causes it to freeze off early and complete the closed system during solidification of the casting and riser.

(3) Position of Blind Heads

64. The photographs of Figs. 39 to 43 illustrate quite clearly the positions of the blind head with respect to the section it is to feed. Some heads are placed at the side of one face of the casting and gated to the flat surface. The head is placed as close to the casting as possible and in a position which makes molding easiest.

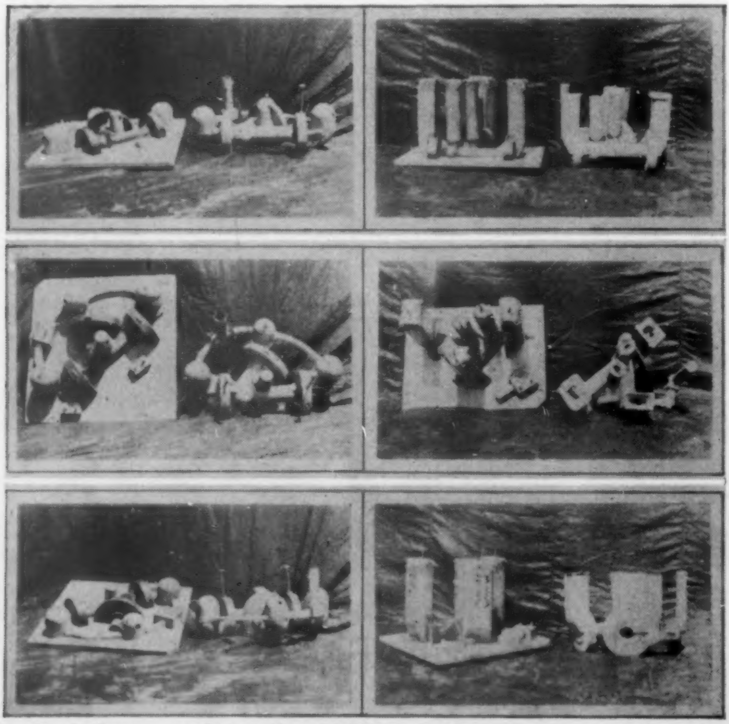


FIG. 39—A COMMERCIAL VALVE CASTING MADE BY BOTH THE OPEN AND BLIND RISER METHODS.

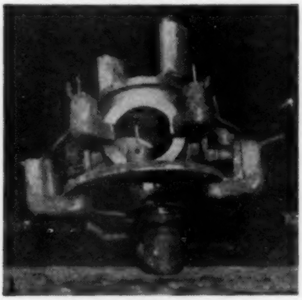


FIG. 40—A COMMERCIAL CASTING MADE WITH BLIND RISERS AT VARIOUS LEVELS IN THE COPE AND DRAG.

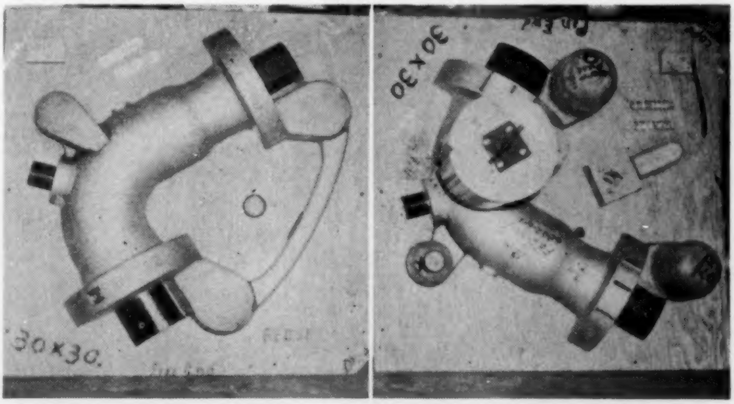


FIG. 41—A COMMERCIAL PATTERN RIGGED FOR BLIND RISERS.

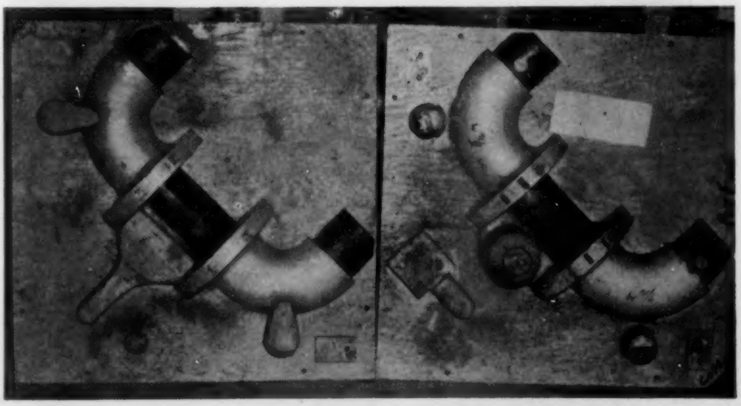


FIG. 42—A COMMERCIAL PATTERN RIGGED FOR BLIND RISERS.

65. The bottom of the blind head may be on the parting line with the neck to the casting entirely in the cope, or it may be partly or wholly in the drag. Examples of all these positions are shown. In general for valve manufacture the flanges are headed partly in the drag and partly in the cope. Fig. 40 shows blind heads at various levels in the cope and drag. For many complicated castings the blind heads must necessarily be made up in cores. The riser may be below the highest part of the section to be fed but, as pointed out earlier, this is usually not the case.

66. When several risers are used at different levels in the same casting it is essential that a particular zone of feeding be relegated to each blind head. Fig. 38 is a sketch showing the necessity for

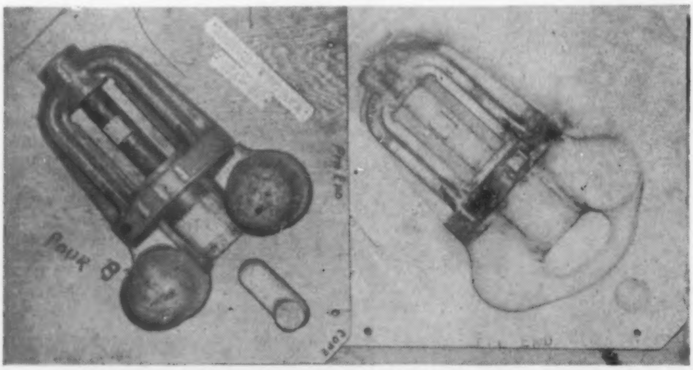


FIG. 43—A COMMERCIAL PATTERN RIGGED FOR BLIND RISERS.

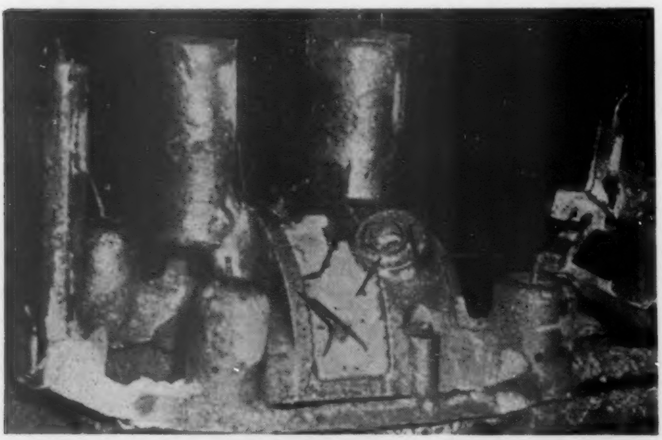


FIG. 44—A COMMERCIAL CASTING MADE WITH BLIND RISERS IN CONJUNCTION WITH OPEN RISERS.

this precaution. The open riser used in this particular case would react similarly if it were a blind type at the same level. This represents roughly an actual casting and the blind riser failed to function, being in fact nearly solid. The cavities were found in the casting and open riser in the positions shown. The reason for this was that since both risers were initially open to the atmosphere, the net advantage of the blind riser in this respect was zero, and due to the greater ferrostatic pressure of the open riser, because of its superior position, the metal was forced through the system to actually feed the blind riser.

67. By the time the narrow section of metal shown at "c" had solidified and shut off the hydraulic contact between the two feed heads metal had solidified beyond the end of the sand core and made it impossible for atmospheric pressure to act. The section to be further fed was choked off at "c" and solidified with the shrinkage shown. The casting could have been made perfectly sound without altering the method of heading in any way. The only change would be to place external metal chills, cast to shape, around the neck of the casting at point "c." This would chill the metal at this point, separate the two heavy sections, and allow each riser to function independently of the other.

Use of Chills

68. The use of external chills is quite often erroneously frowned

FIG. 45—AN OPEN RISER COMBINED WITH A PARTIALLY BLIND RISER FOR FEEDING A YOKE CASTING.

upon, but when properly used, chills can aid greatly in controlling solidification. Since this is not a discussion of chills, no elaboration will be attempted but it is true that several shops apply them with full satisfaction and a greatly enhanced yield of radiographically sound castings. External chills can be used to great advantage in getting the maximum benefit from blind risers but are actually less essential to their satisfactory operation than is the case with open risers since blind risers can be placed wherever needed.

Venting

69. Venting blind head work is essentially the same as for open risers except that thin rectangular "lifter" vents are provided on the upper surfaces of the casting at points shown by the small prints on several of the patterns. The molder's lifter tool is used to make the vent. The blind heads are also vented either with a small lift vent if open risers are incorporated in the system, or with larger round vents, one-half inch or more in diameter, if there are no open risers. The larger vents are used to indicate when the molds are filled. Air and gases must be amply vented so the mold will fill readily and completely.

EXAMPLES OF COMMERCIAL CASTINGS

70. The castings and patterns shown in Figs. 39 to 45 are actual commercial applications of blind risering and show various positions of the blind riser in the mold.

71. The photographs of Fig. 39 show a valve casting made by both the open and blind riser methods. The pictures are intended to afford only a rough comparison of the amounts of metal involved in the two cases as foundrymen would vary greatly in their choice of size, type and number of open risers necessary to make the particular casting shown. They do, however, show the differences between the two methods and indicate a saving in the removal of gates and risers from castings made with blind risers as compared with those made by open risers.

72. Fig. 45 shows an open riser combined with a partially blinded riser for making the yoke casting. The sand core is inserted at the shoulder and insures keeping the system open to the atmosphere. The blind head would have been just as efficient with the smaller vent which is normally used. This particular casting lends itself well to blind head feeding, and is an interesting study in directional solidification. The sections are slightly tapered toward the end away from the risers making satisfactory

feeding from the one end possible. An external cap chill for the boss eliminates the need for a riser at this point and aids the already favorably disposed thermal gradients.

73. The photographs of the various commercial castings and patterns do not necessarily show the only way, or even the best way, of positioning the blind risers but do represent a method which has been applied with complete success. It is axiomatic that the size, number and position of blind risers will vary from plant to plant according to the experience of the foundryman in charge, just as always has been and still is the case with open risers.

74. One very useful application of blind risers which is not shown here is for the elimination of cavities at places where the ingate joins the casting. Because of the enlarged cross-section at this juncture, and because of the metal flowing through, a serious hot spot occurs which often is not fed by ordinary risering. The result is a cavity which may reach to the surface at one of the sharp corners. Contrary to popular belief these enlarged cavities are not caused by volatile gases but by atmospheric pressure forcing its way in to relieve the negative pressure developing from shrinkage at the hot spot. This principle has been clearly discussed above. (Reference Fig. 15 and paragraph 28.) A blind riser placed at this point serves the double purpose of preventing the defect and of acting as a skim gate by swirling the metal through the riser and then into the casting.

Acknowledgment

75. The authors wish to express appreciation to the following men of the Naval Research Laboratory staff: To Harold F. Bishop and Robert E. Morey for foundry assistance, James Darby for melting the metal and Thomas Cunningham for preparing the molds; also the personnel of the Dodge Steel Company for their cooperation throughout the work and for the photographs of commercial castings and patterns included in the paper; to C. S. Roberts and E. C. Troy of that organization, who edited the manuscript and offered numerous important suggestions and criticisms; to Francis M. Walters, Jr., of the Naval Research Laboratory staff for reviewing the work; to H. D. Phillips for bringing the project to our attention at a very early date and for helpful discussions upon the theory and practice of blind risering. The authors are also greatly indebted to the Navy Department for sponsoring the work and for permission to publish the results.

DISCUSSION

Presiding: F. A. MELMOTH, Detroit Steel Castings Co., Detroit, Mich.
Co-Chairman: K. V. WHEELER, American Steel Castings Co., Newark, N. J.

T. D. WEST[1] (*written discussion*): The John Williams riser or the fire cracker head, as so many call it, is a relatively new tool for the steel foundryman to use. This new method of heading has definite merits over the older method of direct risering. The authors have pointed out the many advantages of the patented John Williams riser. Additional advantages are:

(1) These risers can almost always be applied to a flat surface upon which, when the casting reaches the cleaning room, the minimum amount of cleaning is necessary. The fire cracker head can be so attached to the casting as to come up from the under side, on the same horizontal level or directly on top.

(2) Open risers have always been detrimental in a foundry as the stray sand will fall in. This sand may come from the outside of the open riser drying out and the sand falling in, or when a laborer places a weight on a mold he drags it across the top thus knocking more sand down in the mold. The blind atmospheric head will eliminate this danger. Another advantage is that the actual molding cost of the blind riser has been found to be less than that of the open risers. Time studies have proven this. However, some variations in the way the core is placed in the head have been made to help accomplish this. The core is used as a ram-up core, sticking straight down into the head, the right length being ascertained before using. This eliminates the placing of the core in the difficult angle as shown on all the diagrams. This ram-up core is made up of a strong oil sand with a stiff core rod or wire inside of the core.

(3) The danger of shrinkage condition between the open risers and castings in comparison to the blind heads and casting can be eliminated greatly. One reason is that the blind head is always at a constant height and the open riser may be 10-in. high one month and 6-in. high the next month regardless of the amount of supervision there is in a plant. Also, the amount of riser dust greatly affects the feeding effect of an open riser. These variables are not included in the John Williams riser.

(4) However, this riser cannot be used at random, and it takes a little more thought and careful consideration to apply the John Williams riser. The section that is fed must be completely isolated from the rest of the casting either with natural directional solidification, external chill or temperature gradient. The casting has to be studied to see that no internal core will have the reverse effect and feed the head. The writer has seen some cases where an internal core created such a hot spot that the casting fed the head. A green sand core or a thorough venting of the core accomplished the correct results.

(5) Attention should be called to the very hollow gate in Fig. 39 in the center left-hand picture. This is a perfectly natural action where the gate goes directly into the blind risers. The metal, as it goes through

[1] Laboratory, Deere & Co., Moline, Ill.

the pouring gate, heats up the sand so much that it remains open quite long, and the metal in the gate helps feed the blind riser which in turn feeds the casting. This method of gating even utilizes the metal in the gate, a process which malleable iron cannot even obtain. This certainly helps raise the steel foundry's yield.

(6) A new feature is to combine the Washburn core with this type of riser. The size and shape of the opening in the core have to be very carefully studied before releasing a pattern for production. This is extremely helpful in an air-hardening steel as the riser can be flogged off instead of being removed by costly preheating and torch cutting.

(7) The discussion is ever present as to whether it is the gas pressure evolved from the small core or the atmospheric pressure which exerts pressure on the liquid metal in the riser. It is the writer's belief that it is the gas pressure created by the hot metal around the fire cracker core which does most of the work. The burning core gas coming off the vent of the end of the core certainly shows there is more pressure on the inside of the riser than in the atmosphere. If the atmospheric pressure were the greater, the core gas could not get to the surface to burn. These vents burn for quite a while and it is quite some time before the gas issuing from the open vent starts to die down and give the atmosphere a chance to act. However, by this time, the riser would have had a good chance to be solidified.

(8) Regarding valve flanges, the authors state, "In general the mass of the flange is so great that the required blind head is very nearly as high as or higher than the part to be fed." A chill, opposite from the head, on the flange, greatly assists the feeding of the head. The writer has seen a lot of valve flanges headed as mentioned above, and the heads do not extend up to the top of the flange.

The writer would like to question why the auxiliary riser was attached to the top of the blind riser shown in Fig. 45.

H. D. PHILLIPS[2] (written discussion): This is a fine paper, presented in the usual clear, understandable style of the authors and their predecessors at the U. S. Naval Research Laboratory. The subject is, as the authors state, one of the major recent developments in the foundry industry, and their paper should help immeasurably in getting the industry to accept and use the principle involved to the end that steel castings may be sounder and more economically obtainable.

Mention of the present writer's name is sincerely appreciated. While it is only fitting that the name of the one who propounds a new theory and then proves it should be mentioned, it is quite often that credit is given or taken elsewhere.

In analyzing what is new in this development, the following facts must be given consideration:

First, as the authors state, blind head feeding is not new. All steel foundrymen have used it with varying degrees of success. The technical literature is full of illustrations of its use.

[2] Lebanon Steel Foundry, Lebanon, Pa.

Second, the shape of the blind riser is not new. The works of Batty and of Briggs and Gezelius proved years ago that the spherically shaped riser was the best one to use for feeding steel castings.

Third, the point of application is not new. The Lebanon Steel Foundry and others had been applying risers to the faces of flanges and junctions of sections for many years before the knowledge of atmospheric pressure and its effects became known or generally realized. Batty repeatedly pointed out in his work that the riser should be applied to the heaviest section.

Fourth, the principle of directional solidification has been proven and used in many other ways since the published works of Batty and of Briggs and Gezelius have been available.

Fifth, one of the two remaining features of this new technique in gating and risering is the use of atmospheric pressure. This is deserving of some considerable discussion by the present writer to substantiate the previously made statement as to credit for the theory and principles involved.

In 1934, upon entering the employ of the Dodge Steel Company as metallurgist, the present writer found that rejections were being experienced in valves and fittings for the U. S. Navy. After several months, the responsibility for the manufacture of these castings was given the writer. By applying the principles of directional solidification and atmospheric pressure, rejections were soon cut to a very low figure. Previously, pipe eliminator had not even been used on open risers and certain consistent casting defects were ascribed to such vague causes as expansion of molding sand, core blow, etc.

By the use of pipe eliminator on open risers, it was clearly shown that atmospheric pressure was a potent force in the feeding of steel. The barometer effect was also discussed and accepted. These facts have on numerous occasions been verbally attested to by men of the Dodge organization in a position to know of this development work.

Sixth, the use of the small cylindrical core is new, and a very large share of the credit for its conception and utilization is due to John Williams of the Dodge Steel Company. This feature and this alone has been patented. Late experiments indicate very definitely that this is not the only means which will function with a high degree of certainty and simplicity in keeping a blind head open and here exception is taken to the authors' statement. Any foundryman, with a keen appreciation of the principles of directional solidification and the laws governing the behavior of liquids, can devise means of accomplishing the same purpose.

There are a lot of points in this paper worthy of considerable discussion, such as early and late feed demand, etc., but time does not permit it.

In closing, while it is unfortunate that full utilization of this principle has not been generally accepted, this paper should promote such an interest, by its complete handling of the subject, that nought but full and proper usage should immediately result.

While, as the authors state, there are some disadvantages that result from the use of this style of gating and risering, nothing but advantages

can result from a full knowledge of the use of atmospheric or greater pressures in feeding steel castings, and the authors are deserving of the thanks of the industry for explaining it so clearly and completely.

It is interesting to note that the authors are not so definite in this paper as they were in the paper presented by them before the Steel Founders' Society of America in the statement that the patented core is the only means which will function with a high degree of certainty and simplicity in keeping a blind head open. There are many other ways, as they now mention, which will do the same thing and avoid the patent.

CHAIRMAN MELMOTH: I do not know of another subject that is quite as important as the feeding of steel castings. The increased severity of inspection by X-rays and gamma rays has made a foundryman's life somewhat of a nightmare, and, when one gets down to facts, a very large proportion of the troubles which are shown up by that type of inspection can be directly attributed to improper methods of feeding. We have used this head a great deal and have found sufficient proof of its advantages to continue to use it and to keep on trying to enlarge the scope of its application.

MR. PHILLIPS: From my own experience, I know that many foundrymen have tried to use blind heads and this patented core with little or no success, and upon checking into their attempts, have found that they have ignored the early and late feed demand features and the gravitational effect. The authors cover that, although in my estimation, it could have been more completely covered for the practical foundrymen. They have included one illustration in the paper, but it should be more clearly shown that, in using an open riser high in the cope and a blind riser at the joint, the fact must be recognized that the open riser in the cope is in a superior position to the blind riser and will feed that blind riser until solidification cuts off the gravitational effect between the open riser and the blind one. Those things must be recognized in using this method of risering.

There are a lot of disadvantages resulting from the use of this method of gating and risering. It does not work as well on massive castings as it does on lighter sectioned castings. Those who have tried it have failed to secure the same beneficial results that one gets on the smaller castings, even though they have taken into consideration all the rules governing its use. It is a matter of temperature gradients.

There is another disadvantage that we have had experience with in our shop in trying to feed large castings, namely, sticking a core into a blind head 12-in. or more in diameter and having it fail to work because of the mechanical failure of the core. We have overcome that in a method distinctly unique. Instead of having the core stick into the center of the mass of the riser, we have the core stick completely through the riser, and instead of having it of material chemically inert, we make it of material which is not chemically inert. The carbonless pipe eliminators can be used. They actually increase the efficiency of the riser, and this method has proven to work with great simplicity and certainty.

Another disadvantage to the use of totally blind risers is in green sand work on small castings poured at high temperatures. Unless suffi-

cient vents are carried off from the mold, porosity may be encountered.

I could mention quite a few such disadvantages but instead of doing that, I want to take the position of approving and endorsing the principle of using atmospheric pressure in the feeding of steel castings.

P. D. DEHUFF[3]: In Fig. 45, the authors show a blind riser with a "flow-off" coming off the top of the riser. It is noticed that in all illustrations previous to this, the authors do not make use of these "flow-offs" on all of their risers. They use only the cylindrical top on the riser. Is the aforementioned "flow-off" a good means of removing the slag from the top of the riser, thus preventing the slag from being entrapped in the casting?

MR. PHILLIPS: I would interpret the use of those large "flow-offs" in Fig. 45 as a practical insurance in the working of this blind riser. In our experience, theoretically, it is possible to feed quite high above the riser. If a bit of sand or slag gets in the top of the flange shown, it could admit the atmosphere to that section of the casting, and if the riser were in a lower position, it would result in improper feeding. The atmospheric pressure would be applied at two points, so I think what they tried to do in that case is to take some practical insurance against that happening. Sometimes sand washes away and lodges in certain critical sections of the casting. I would say what the foundryman has tried to do is to bring into play hydrostatic head along with atmospheric pressure.

CHAIRMAN MELMOTH: This paper is not necessarily advocating or dealing essentially with the use of a core or any method of applying the principle. What it is really intended to do is to bring home to foundrymen the distinct advantages that come from a knowledge of the principle. We could almost forget the mere use of a core or anything of that type. To me, the whole method had a value in giving me an explanation of something which I never believed, that there was any value to the use of pipe eliminators. They were sold at one time largely on the basis of producing some sort of exothermic reaction. If they had been sold on the basis of keeping the riser open so that atmospheric pressure could become operative, they probably would have been much more generally used. I believe that is the point the authors are trying to get across, namely, an understanding and knowledge of the principle involved, and I assure you it is very well worth while. If practical foremen responsible for methods of gating and heading can once get the hang of this atmospheric pressure method of feeding, there is no question but that it will rapidly improve practice from many standpoints.

M. J. GREGORY[4]: We all know that blind risers and open risers have been used in high grade malleable and gray iron for many, many years. Therefore, I am rather interested in hearing this discourse, but the thing that intrigues me is this patent gate or core. Is the steel industry restricted in using it, is it a license, or is it something that perhaps is kept from others, that placed the steel industry in a somewhat chaotic condition when it came to getting sound castings? I would like to know more about the patent core or the patent.

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3 Lehigh University, Bethlehem, Pa.
4 Caterpillar Tractor Co., Peoria, Ill.

CHAIRMAN MELMOTH: I think it would be quite possible to put you in touch with the company that has control of this particular thing and they will tell you all the facts very much more reliably than the author or I could tell you. We could tell you how it operates from the steel industry standpoint.

S. W. BRINSON[5]: The authors talk about the atmospheric pressure overcoming gravity and feeding up into the casting from the blind riser. Would it not be more successful to cooperate with gravity than to start opposing it by going too far with a blind riser? The open riser cooperates with gravity. One might as well take advantage of it.

One of the greatest things about the blind riser described and one of the greatest success factors, is not the question of the use of the patented core, but it is something that has been put before us for many, many years, namely, the fact that hot metal enters the riser by bottom pouring. That is the main success. If care is not exercised, it is possible to get atmospheric pressure in the riser and sometimes in a casting where it is not wanted by a blow through a hot spot that will give the same effect as this core. The greatest success comes in getting hot metal in the riser. If it is hot enough, it will come through somewhere. We all, at times, whether we want to or not, have to use blind risers, and we would rather know these things in case we do have to use them, so we know how to take advantage of them and get the best results.

CO-CHAIRMAN WHEELER: We have used blind risers or side risers for years. I go back 25 years, and I do not think I am the only one in the audience. We got certain results from the use of those side risers or blind risers, but credit is due to the authors of this paper and to the people who have developed the use of atmospheric pressure in connection with blind risers. The foundry industry owes a lot to them because foundrymen have been stimulated to think along more scientific lines in the handling of their heading and gating and designing of castings to get solid sections. I believe that we owe a lot of thanks to those who are responsible for bringing it to our attention, both before, and now to the authors of this paper.

MESSRS. TAYLOR and ROMINSKI (*authors' closure*): The authors are indeed grateful for the interesting and valuable discussions of their paper.

Mr. Phillips' word of warning about the use of blind and open risers on the same casting should be heeded, for, unless proper provision is made, open risers in their superior position may feed blind risers and cause them to be ineffectual. However, it is usually possible to guard against this by a judicious use of external chills. We believe this principle is explained fully enough to prevent a foundryman from making this mistake and to clarify the mistake if it is made. It would have been well to have illustrated the principle by using interconnected open and blind risers. For example if the casting of Fig. 4 had been extended to the surface and kept open to the atmosphere it is easy to see that it would have fed the blind riser and prevented its effectiveness. This illustrates

[5] Norfolk Navy Yard, Portsmouth, Va.

the case under discussion, except that the risers would be separated by a section of the casting. Individual zones of feeding can be relegated to each riser by suitable chilling.

The method described by Mr. Phillips for keeping risers open is certainly as good as any other mentioned, and, as he points out, adds mechanical stability and increases the efficiency of the riser by an exothermic reaction.

Since the "flow-off" mentioned by Mr. DeHuff is placed above the blind riser, it would add nothing as a possible slag trap that would not exist in the blind riser with the enclosed cylindrical top. The slag would collect in one as readily as in the other. As Mr. Phillips mentioned, the use of the large "flow-off" provides added ferrostatic head. Although this is not necessary, it may often be an advantage. The greatest value of this practice is that it affords a means of knowing when the casting is nearly full so pouring can be stopped gradually. This is provided by a one-in. vent, however. The casting shown in Fig. 45 could be made just as satisfactorily without the large open riser.

The authors are especially appreciative of Chairman Melmoth's interpretation of their efforts, and, in particular, for his statement that their interest was in furthering "an understanding, and knowledge of the principles involved" in atmospheric pressure feeding.

To say, as Mr. Brinson does, that the "main success" of blind risers depends upon getting hot metal in them, is to state a fundamental truth governing all risers. The great difference in respect to hot metal is that for obvious reasons it is much easier to obtain this condition in blind risers than it is in open types. If adequate feed metal is provided, proper thermal gradients will always insure sound metal. As an indication that atmospheric pressure is a valuable influence in proper feeding, one has only to glance at Fig. 7 and refer to paragraphs 23 and 24. Heat gradients do not initially favor the riser in this example and yet the riser has very nearly completely fed the casting. Figures 25 and 27 show schematically how shrinkage takes place with and without the riser being open to the atmosphere. Although the actual casting made as indicated in Fig. 27 is not shown in the paper, it is on exhibit at the Naval Research Laboratory. Here, then, are two identical casting riser systems, except that the riser of Fig. 27 is not kept open to the atmosphere. In this case although the hottest metal is in the riser, the same as is the case in Fig. 25, feeding is not adequate. This is shown even more strikingly in Fig. 29 where the casting is even lower than the riser. It is clear then that atmospheric pressure is a potent factor, and, although hot riser metal and proper thermal gradients are necessary, these have long been recognized as prerequisite for any method of feeding. That the riser will break through from natural causes and without any artificial means being provided when extremely hot metal is used is true enough, but that it may not do so is equally true. In the authors' opinion it is well to provide some form of insurance.

Several of the points brought out in Mr. West's written discussion are worthy of much greater consideration than was given by the authors. However, many of the points which he regards as "additional advan-

tages" of the blind riser are touched upon in the text. The question as to whether gas pressure evolved from the core is responsible for assisting feeding rather than atmospheric pressure, we believe, is answered by Fig. 18 and paragraphs 32 and 33 of the text. In the case illustrated there was no excessive gas pressure developed from the alundum sheath. Also sand cores bonded with bentonite work fully as well as cores bonded with a volatile, gas-forming binder. It is natural that any gas pressure developed in excess of atmospheric pressure is a push in the right direction, but it is true also that it is not necessary to insure proper results from atmospheric pressure feeding.

Concerning the ninth paragraph of Mr. West's discussion, perhaps a better way of stating the thought is "Often the mass of the flange is so great that the required blind head is very nearly as high or higher than the part to be fed." That this need not be the case is clearly indicated.

Design of Core Boxes and Driers for Core Blowing Machines

By O. A. Van Sickle*, Detroit, Michigan

Abstract

The proper design and selection of core box equipment for core blowing machines requires skill, experience and cooperation of foundryman, coremaker and patternmaker. A blow box can usually be classified as (1) open face type, (2) vertical split type, or (3) horizontal split type. Some important considerations in designing a blower core box are location of the parting, size and location of blow holes and exhaust screens and selection of the available machine best suited to blow the type and size core required. Other factors to facilitate production are the use of two lower halves of the box or the use of exact size driers instead of the lower half of the box.

1. Economical and efficient design of core box equipment for core blowing machines requires skill, experience and complete cooperation of foundryman, coremaker, and patternmaker.

2. Too frequently, equipment is purchased, and, when received, found to be wholly inadequate because of faulty design or construction. The blame for this situation is with the buyer and not with the maker of the equipment. Criticism and second guessing are only wasted effort, and both time and money are spent putting the job into condition so that it can be used as was intended. If a complete drawing cannot be made, a few sketches will aid in getting well constructed and satisfactory equipment.

3. When laying out a job for blowing machine cores, it is well to keep in mind that strike-off faces or filling openings require practically no consideration and, because of this, it is possible to blow a core in one piece which would otherwise have to be made in two or more pieces requiring rubbing, pasting and assembling operations and fixtures.

Composition of Core Box

4. Boxes should be made of metal, aluminum or magnesium, weight usually being the determining factor. Outside surfaces should be machined square and parallel to properly locate or clamp

* City Pattern Works.

Note: This paper was presented before a Patternmaking Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 20, 1942.

in the machine. They should be well ribbed and solidly constructed throughout, as they will be subjected to much abuse in handling to get the most efficiency in production. The parting joint should be at least 1-in. wide, steel faced and well spotted together to provide a tight seal and prevent seaming of the core.

TYPES OF BLOW BOXES

5. Generally a blow box for blowing cores can be placed in one of three classes:

(1) The open face or dump type, such as a cover or chunk core.
(2) The vertical split type, such as bearing or pin cores.
(3) The horizontal split type, good examples being jacket or pipe cores.

DESIGNING THE BLOWER CORE BOX

6. In designing a blower core box, the first step is to determine the parting, then select the available machine best suited to blow the type and size core required. Examine the method of holding or locating the box in the machine and provide chucking surface or stop pads where needed. If the box is to be drawn on a core box drawing machine, bosses or pads will also be necessary. Handles will be required on some boxes, and these can either be cast on or fastened on after the box is completed. Also, where the core must be vented, bosses must be provided for the vent wire bushings. It is good practice to make the vent rod bushings of rubber to provide a tight seal around the vent rod. This is especially true for vent rods of $3/8$ or $1/2$-in. diameter that are in position when blowing the core.

7. After these preliminary steps, each job will require individual consideration and, in some cases, much experimental work, as cores now being blown successfully range from less than 1 oz. to over 300 lb. in a wide variety of shapes and sections.

BLOW HOLES AND EXHAUST SCREENS

8. Size and location of blow holes and exhaust screens is an individual problem depending on the size and cross sections of the core as well as the type and mixture of sand used.

9. Blow holes range from $\frac{3}{16}$ to 1-in. in diameter and are usually placed over the largest and deepest sections of the core, using as

few as possible. Many types of blow bushings and tubes are used with satisfactory results, but very efficient and inexpensive tubes can be made of common seamless steel tubing, pressed in and capped with a $\frac{1}{8}$-in. thick steel washer, the inside diameter of the washer being the same size as the hole in the tube and the outside about $1\frac{3}{4}$-in. These steel washers provide a good seal around the holes in the blow plate and are easily spotted down or replaced when worn. They are held in place with three flat head screws and are interchangeable except for the inside diameter so that they can be made up in quantities and kept in stock.

10. Exhaust screens also are from $\frac{3}{16}$ to 1-in. in diameter and several types are on the market. All are efficient and a stock of each should be kept on hand as some can be used in certain places better than others. The locating of exhaust screens as well as size and number is also a separate problem with each core and requires experimenting with a few samples. It is a good policy to start with a few small screens placed in corners and places where air is liable to be trapped, try a sample and examine it for soft spots, then add to or enlarge the screens at or near these soft spots. If the air is exhausted too rapidly from the box as the sand is forced through the blow holes, it will cause a blasting action and much unnecessary wear on the box. However, it is often necessary, especially in shallow boxes, to place steel wear pads directly under the blow tubes. A disc type pad for this purpose will be found quite easy to install or replace after showing signs of wear. Experience is most essential in screening a blow core box, as size and shape of core, sand mixture and air pressure being used must all be considered.

METHODS OF INCREASING PRODUCTION

11. When the box is to be used on a draw-type blow machine it is often possible to speed production by having two or more lower half boxes to one upper. The upper half box is fastened to the head of the machine and while one core is being blown the other is being drawn, loose pieces or ram-up driers are being put in place and the box otherwise being made ready to be blown again.

12. It is also possible in many cases to speed production by dispensing with the lower half of the box and blowing directly intc the drier if the drier is made to exact size. In this method of blowing, proper size and location of blow holes and exhaust screens is very important. In making core boxes, the vents, if possible, should be inserted so they can be blown out from the opposite side. The

particles stuck in the vent will be cleaned out better in this manner. This method is more satisfactory than trying to blow through the vent where the particles are already imbedded. Very little if any screening should be done in the drier and much wear on driers can be eliminated with well placed and proper size blow tubes. The driers used must be solidly constructed, well ribbed and bosses provided for installing steel bushings for the core box pins. The parting flange should be at least 1-in. wide and machined or well spotted and provisions made for clamping or locating in the machine.

CONSTRUCTION OF CARRIER DRIERS

13. Construction of carrier driers for blow machine boxes is practically the same as for other core boxes. They should be as light as possible and well ribbed to prevent warping. A clearance of $\frac{1}{32}$ to $\frac{1}{16}$-in. should be allowed all around carrier driers with a $\frac{1}{16}$-in. radius at the top. The drier should be cut down $\frac{1}{16}$-in. below the joint line all over the face except for fitting pads about $\frac{3}{8}$ x 1-in. to be left at intervals where they will be easy to file and aid in straightening. Small holes countersunk from the outside and spaced about an inch apart will provide better heat distribution when drying the core and also eliminate weight. Before fitting all driers should be annealed in an oven at about 500°F. for at least 4 hours to relieve strains and prevent warping.

14. Blowing cores is confined strictly to quantities and if the production demand is sufficient, equipment can be developed to a very high degree. However, as most foundries are of the jobbing type, cores are usually required in small quantities and this entails frequent changing of core boxes and blow plates. Therefore, in designing boxes for the lower production jobs, many methods can be developed whereby several similar boxes can be blown on the same machine without too frequent changing of the blow plate or adjusting the locating stops or clamps.

CONCLUSION

15. In conclusion, it may be stated that the design of blow core boxes, as of most foundry equipment, depends largely on the plant itself as well as the cooperation, experience and ingenuity of all persons involved. The proper design, making and use of the equipment and sufficient time spent at the start of the job will produce gratifying results.

DISCUSSION

Presiding: FRANK C. CECH, Cleveland Trade School, Cleveland, O.

Co-Chairman: V. J. SEDLON, Master Pattern Works, Cleveland, O.

MEMBER: Have you ever used carboloy inserts for blowing holes?

MR. VAN SICKLE: No, I do not think there are any. Maybe on a very high production job, but the automobile industry is about the highest production job in blowing cores and I have not seen any hardened tubes.

MEMBER: They are being used.

MR. VAN SICKLE: It is too easy to change them. Common seamless tubing is just pressed in and it is no trick at all to press it out and put in a new one. One tube is probably good for 200,000 or 300,000 cores.

MEMBER: In regard to evacuation of air causing wear on the box, is it not necessary to have rapid evacuation in a core to pack your core solid?

MR. VAN SICKLE: There is a point there. It is difficult to determine when just enough air is being exhausted and enough is still being held back to keep from the blasting action. If your air exhausts too rapidly from the core box, the box will wear much faster. That point is very hard to determine.

J. E. KOLB[1]: Have you ever attempted, before blowing the core, to calculate the amount of sand blown into the box relative to the amount of air exhausted from the box and the air pressure behind it; the area of the blow holes and the area of the vents?

MR. VAN SICKLE: No. But I would like to hear comment from someone who has, to see if anything can be worked out along those lines.

MR. KOLB: There seems to be quite a difference of opinion. It is the general consensus of opinion to put as many vent holes in a box as possible; that is, without putting them in the side of the box where it will interfere with the draw and have a tendency to leave a rough surface on the side. In different instances, we have tried to arrive at the smallest number of vents to keep away from the abrasive action which acts as a sand blast in blowing the sand into the box; keeping the sand moisture and air pressure under constant control has quite a bit to do with it. In one sense of the word, we have to allow a little bit more vent to take care of a slight variation in moisture and air pressure. We have quite a variety of work. We run one job possibly 1½ or 2 hours on a blower and leave the same plate on the magazine with a separate blow plate over the face of each box.

It is quite a common practice for people who are just starting in with the blowers to drill holes promiscuously about the plate without giving any thought to regularity. After considerable experience, we laid out the blow holes in a symmetrical manner in the magazine plate, whereby we could substitute any position of a hole in the blow plate over the box. Has anybody else had that same experience?

MR. VAN SICKLE: That is usually up to the individual shop. It all depends upon the type of work. Perhaps there are similar boxes that can be run that way. In some cases, slots are put in the blow plate. In blow-

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[1] Caterpillar Tractor Co., Peoria, Ill.

FIG. 1—LOOKING UP UNDER MAGAZINE OF CORE BLOWER MACHINE, VIEW OF TOP HALF OF TWO DIFFERENT CORE BOXES MOUNTED ON THE SAME BLOW PLATE, PERMITTING THE BLOWING OF TWO CORES AT THE SAME TIME.

ing a pin core box, there is one box with five or six cores and another with eight or ten. Maybe the spacing on one is an inch apart and on the other it is only ⅝- or ¾-in., just put a slot down through the plate and, as long as the box is made symmetrically from the locating side, the row of pin cores can be blown right through a slot. There are a lot of cases where part of the holes are used and then the blow plate is put on top of the box as a stopper for certain holes. It is usual though in an open face box.

M. J. GREGORY[2]: The speaker has brought out the point as to the number of cores and changes. I would like to bring out the point of venting core boxes.

We will attempt to convey and illustrate a system of blowing and venting cores and core boxes we have found to work out very satisfactorily. Figure 1 shows assembly of blower magazine, magazine plate and blow plate, on which the core box is mounted. The magazine plate is constructed to fit on the magazine and is completely drilled with equally spaced holes as shown in Fig. 2. The purpose of these holes will be explained later. The blow plate is fastened onto the magazine plate. Note that this plate is the same size as the magazine plate. The blow plate has only the number of blow holes in it necessary to blow any given core box. You can now see that any desired hole location or series of holes in the blow plate can be made to coincide with the corresponding hole or holes in the magazine plate.

[2] Caterpillar Tractor Co., Peoria, Ill.

It can be readily seen that all the holes in the magazine plate are not required to blow the core, as is illustrated in Fig. 2, so the holes not needed are automatically shut off by the blank, or solid space of the blow plate. Consequently only one magazine plate is required, but every core box must have its own blow plate.

This arrangement is for use with a two piece core box, or, a top half and bottom half of core box where the sand is entered into the core box in a vertical position, or, blown directly in the top of box. Then we have the bottom half of the box. This half of the core box is placed on the bed of the machine located by a system of stops to align bottom half with top half, until the bed of the machine is raised and both halves are perfectly aligned by pins and bushings in halves of box proper. Let us bear in mind that the core box itself need not be a two-piece or split-type affair. An open face, or, we might say, a dump-type box works equally the same, the blower plate acting as the top half and the complete core box as the bottom half. The air and sand are now ready to be blown into the core boxes.

Suppose we discuss one more phase of blowing cores. We at the Caterpillar Tractor Co. think nothing of blowing 35 or 40 cores, then changing and putting another box on the machine and blowing 35 or 40 more, because, after all, this is the class of work we have in production, and we find this setup very profitable.

FIG. 2—VIEW OF TWO OF THE BLOW PLATES THAT MOUNT ON THE MAGAZINE PLATE. THIS MAGAZINE PLATE IS UNIVERSAL, FITTING ALL BLOW PLATES MOUNTED ON CORE BLOWER MACHINE. NOTE VENTS IN SIDES OF PLATE.

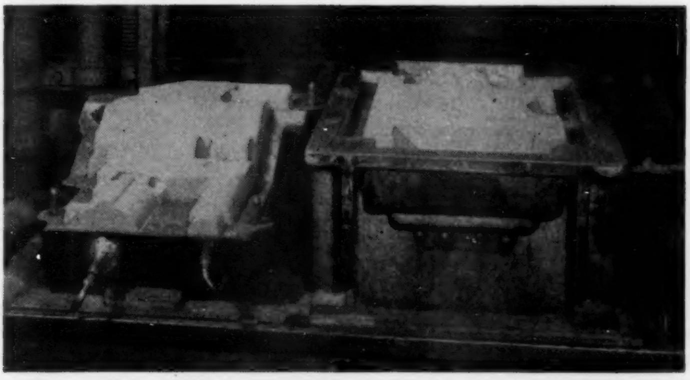


FIG. 3—CORE BLOWN BEFORE DRIERS HAVE BEEN PLACED INTO POSITION.

First of all we have the blower magazine again. Onto the magazine a magazine plate is bolted such as is shown in Fig. 5. This magazine plate differs from the one previously explained, inasmuch as it has one large sand opening instead of many small sand openings. It differs again in its construction as it has two slotted flanges to accommodate the blow plate as shown in Fig. 5. This blow plate is a flat piece of steel onto which the core box is fastened. Note the four set screws "A" on each flange of magazine plate. By loosening these screws the blow plate may be removed from slots and a different blow plate substituted. In other words, one magazine plate with a particular sized sand opening hole, will accommodate as many core boxes as the contour of the hole will best fit the arrangement of blow holes in the core box. So, to sum up, one magazine plate is required for a certain range of core boxes; but another is required for a different range.

It is very practical to ask a coremaker who is going to have anywhere from 7 to 15 changes a day, to arrange his core boxes of a size that will take a particular sized hole in the magazine plate, thereby eliminating any change to the magazine plate for the entire day's run. In the event that a job having only 25 or 30 driers has been blown, and there are several jobs of this nature to be run, it is a simple operation to loosen the four screws on each of the two flanges of the magazine plate and slide the entire blow plate, with core box attached, out of the slotted flanges and substitute the blow plate for the next job. Tighten the 8 set screws and the second job is ready to be blown. The change of set-up requires about 5 minutes at the most. You can readily see how this arrangement works with comparative ease.

Now that is one way of going into the jobbing business and doing a very profitable job. A high production such as in the automotive business is not necessarily essential to prove out very satisfactorily.

In our first experience with one machine, working on an average of approximately 12 hours a day, we were able to save $10,000 in one year with one machine. However, it cost us $9,000 to do all our experimental

work to arrive at something that might speed up the job. With an expenditure of $9,000 and a saving of $10,000 it told us we were on the right track.

Now suppose we take up the venting of core boxes to dispense the air that has been blown in. I believe that one of the greatest mistakes we have all made in core blowing is trying to see how few vents we can put in a box and how much air pressure we can use in putting the sand in the box. The results were that we had a sandblast action rather than core blowing. Today we attack that problem from a different angle. We have found that the best theory, as well as the best practice, is to have plenty of vent holes in the bottom half of the core box.

In blowing sand down into the core box, air is also being blown in. With vent holes in the bottom of the box, and sometimes in the side, the sand is going in and the air is going out through the bottom. Now there is also air coming up the top. It cannot be helped. Air will go out through the bottom as well as the sand going down. But air will come out through the top, and it is very important to put vents in the top half of the box, also.

We will assume that we have vents through the top half of the box, of course, not conflicting with the ordinary steel tubing that is in the blow plate or the top box. But we will carry these small vents in through the plate and out through the side of the blow plate. (See Figs. 1 and 2.) Thus, you have air going out the bottom as the sand comes in and air that is rising through the top and coming out through the side of the plate.

You can blow cores very successfully with proper venting with 65 lb.

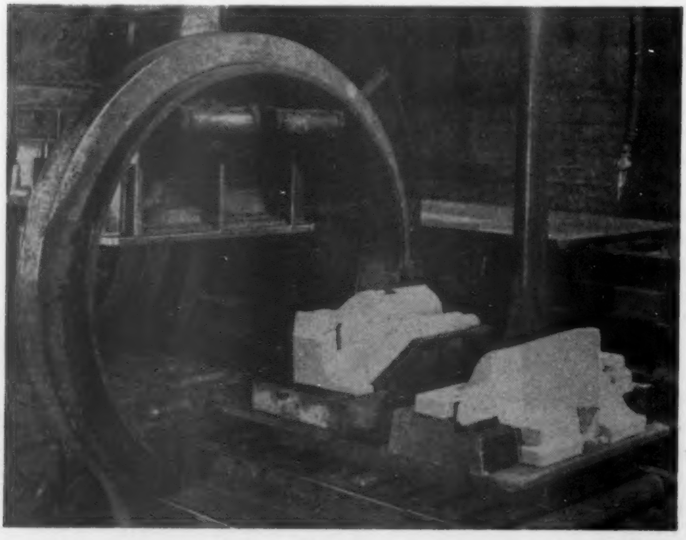


FIG. 4—COMPLETED CORE AFTER GOING THROUGH THE OPERATION OF ROLLING OVER AND DRAWING CORE BOX, READY FOR THE CORE OVEN.

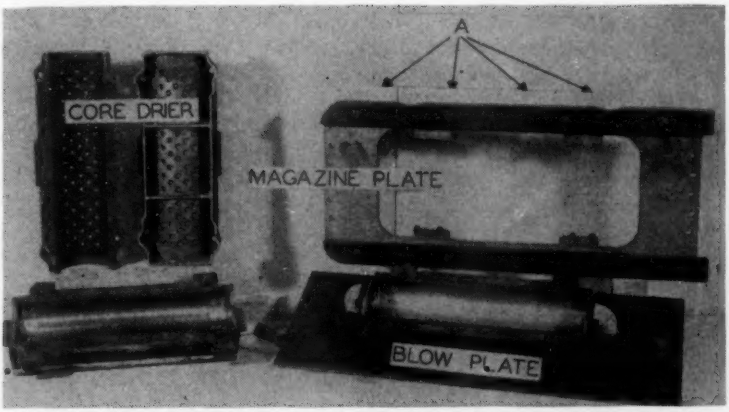


FIG. 5—VIEW OF CYLINDER LINER CORE BOX MOUNTED ON BLOW PLATE AND MAGAZINE PLATE WITH SLOTTED FLANGES FOR HOLDING BLOW PLATE IN POSITION.

of air pressure. A few years ago, when we had trouble, we put boosters in the air line to increase the pressure to 125, and, in some cases, to 150 lb. per sq. in. All we had was sand blastings and we were wearing out our boxes. So we have vents going through the bottom. Air that naturally rises to the top goes through the vent holes into the top of the box, out through the top and out through the side of the plate.

That is what we think is a fairly successful way of blowing cores, using as many vents as possible. Do not hesitate to put all the vents possible in a core box. They do not cost very much. We realize brass is hard to get but maybe we can use steel if we have to.

VAUGHAN REID[3]: In putting a lot of vents into a job of that kind, remember that the more openings there are, the more air that will blow

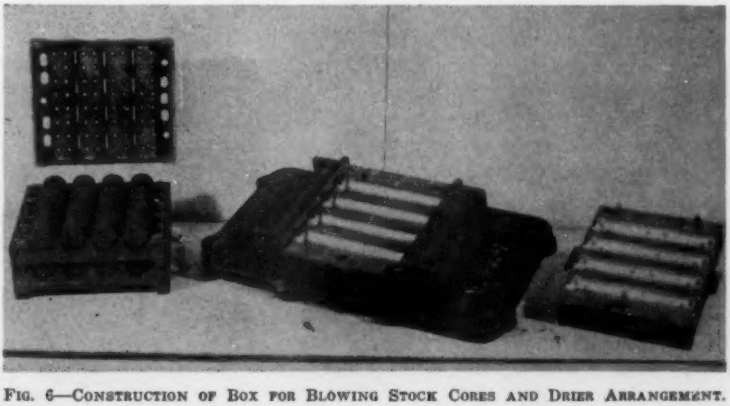


FIG. 6—CONSTRUCTION OF BOX FOR BLOWING STOCK CORES AND DRIER ARRANGEMENT.

[3] City Pattern Works, Detroit, Mich.

through. So there is a happy medium in all things. The more air blown in, the quicker the core box will wear.

These holes through which the sand is blown in hit the core box at some point or other. Those points are going to show worn spots very quickly if the air comes out too quickly. So there is a spot where it is necessary not to put too many outlets.

MR. GREGORY: I will accept that as a constructive criticism. However, I would like to say there is no such thing as getting too many vents. The more vents you get in, the easier it will be on your core box.

I want to bring out one more point. Cylinder liners are cast on the horizontal, using a dry sand method where the tolerance of the casting is 0.018-in. The operation is successful in the foundry as well as in the machine shop. I want to bring out how that core is blown, especially as it has a bearing on the wearing of the core box. It is not necessary to have a stock core to do this particular job but naturally it should be a core that lends itself to the job.

To better illustrate the point I want to bring out, suppose we adapt a core box to the blower machine. This box is to make a cylindrical core, 4-in. in diameter and 12-in. long. This box is going to be blown in a horizontal position with the blow holes coming down directly through the top half of the box.

With blow holes in that plate blowing down into the core box, it can be seen that the sand is going to go down and hit the bottom of the box, and where that stream of sand hits the bottom of the box, whether it is at high pressure or low pressure, it will wear very, very quickly. We found after 500 or 600 cores, we were ready to buy new core boxes.

Figure 3 shows the core box blown in a horizontal position, but from each end by use of two cast iron elbows or sand inlets. In other words, the sand is blown around a corner. The sand coming in each end meets in the center of the box and naturally backs up like a rubber ball. There is no abrasion on the core box. It is nothing unusual to blow 10,000 cores and find no wear at all on the core box and still, with the sand traveling around this angle and shooting in, it is surprising how long these cast iron elbows will last. This proves that if the sand has a free movement or the air can get out quickly, you have less wearing. Pay particular attention to the position of the vents around each end of the core box.

As the sand blows in towards the center and then the sand backs out towards the end, it forces the air out, and the air comes out through the end of the box.

It is possible to blow a stock core, from 1½-in. up to any diameter, by that particular method. I do not think there can be too many vents in a core box. The more vents, the less abrasion and wear.

Salvage and Reclamation of Aluminum Alloy Castings by Welding

By A. T. Ruppe* and A. J. Juroff,** South Bend, Ind.

Abstract

In these times of National production effort, the salvage of all products is an important item. In this paper, the authors explain the methods used by the company with which they are associated to salvage aluminum alloy castings by welding. They describe the proper technique for the reclamation of a defective casting and also the quality of the weld that can be expected when the welding is done by an experienced man. Test bars used in the investigation were cast in green sand molds in accordance with U. S. Army Specification No. 57-72. To show the effectiveness of the technique on various types of aluminum alloys, test bars and castings were radiographed to show the quality of the welds. In addition, the strength properties, both welded and unwelded, of the test bars were determined to obtain information as to the effect of welding.

1. Among the many questions which confront the non-ferrous foundryman when he considers the problem of salvage and reclamation of aluminum alloy castings by welding, there are two which seem to be the most common. The first is concerned with the physical properties of the weld and the second with the consistent production of clean, sound welds. Radiographic inspection can provide adequate protection against defective welds, and much has been written on x-ray and gamma ray weld inspection. However, there is very little specific information in the literature on the physical properties of welded casting aluminum alloys.

* Assistant Foundry Superintendent and ** Metallurgist, Products Division, Bendix Aviation Corporation.

Note: This paper was presented at a Non-Ferrous Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 21, 1942.

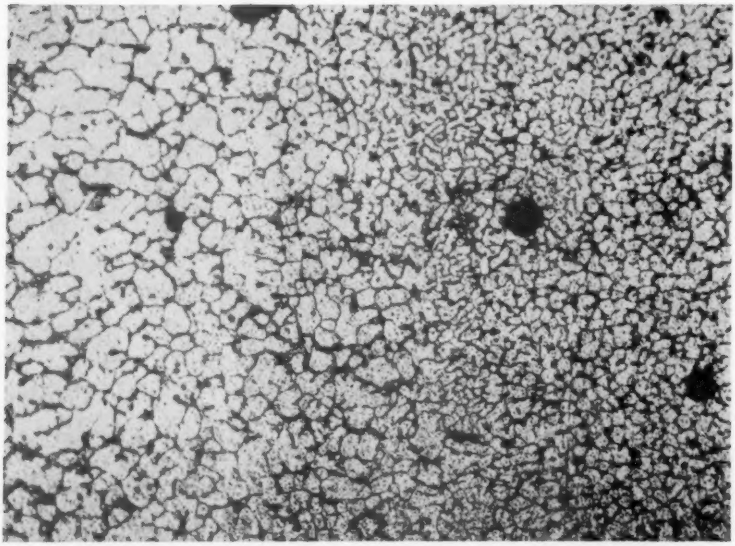


FIG. 1—STRUCTURE OF WELD IN A 5 PER CENT SILICON ALLOY. MAGNIFICATION, x75.

2. It is the purpose of this paper to present data showing the physical properties of cast and machined tensile specimens of three common aluminum casting alloys in the "as-cast" condition and to compare these properties with those of similar specimens which had been cut in half, or notched, and butt welded. The information presented herein is at best incomplete, and represents only the preliminary work done on the subject.

3. Two examples of welded castings are included to illustrate:

1. The type of foundry defect that can be welded, and
2. The quality of weld that can be expected when the work is done by an experienced welder.

EXPERIMENTAL PROCEDURE

4. The test bars used in these experiments were cast in green sand molds according to U. S. Army Ordnance specification No. 57-72. They were of standard design when cast, having a ½-in. shank diameter, a 2-in. gauge length and ¾-in. stubs.

5. A portion of the test bars of each alloy were cut in half, single "vee" notched or double "vee" notched and then welded

together. Each bar was welded using a rod having the same nominal chemical composition.

6. After welding, the Nos. 195 and 355 alloy bars were heat treated. The heat treatment of the 355 alloy consisted of a 16 hour solution treatment at 980°F., a hot water quench and artificial ageing at 325°F. for 6 hours. The 195 alloy bars were given an 18 hour solution treatment, a hot water quench, and were aged at 300°F. for 4 hours.

7. Because it was not thought suitable to pull a welded test bar with a bead left on the joint, all test bars, both the welded and the "as-cast" units, were machined to a shank diameter of 0.400-in. plus or minus 0.010-in. In this manner, the strength of a machined tensile specimen, which is normally somewhat lower than that of an "as-cast" specimen, was determined.

8. All the test bars were radiographed before the tensile test, and those bars which would not pass an ordinary radiographic inspection were discarded. A few specimens containing small defects in the weld metal were retained to observe the effect of slightly porous welds on the physical properties.

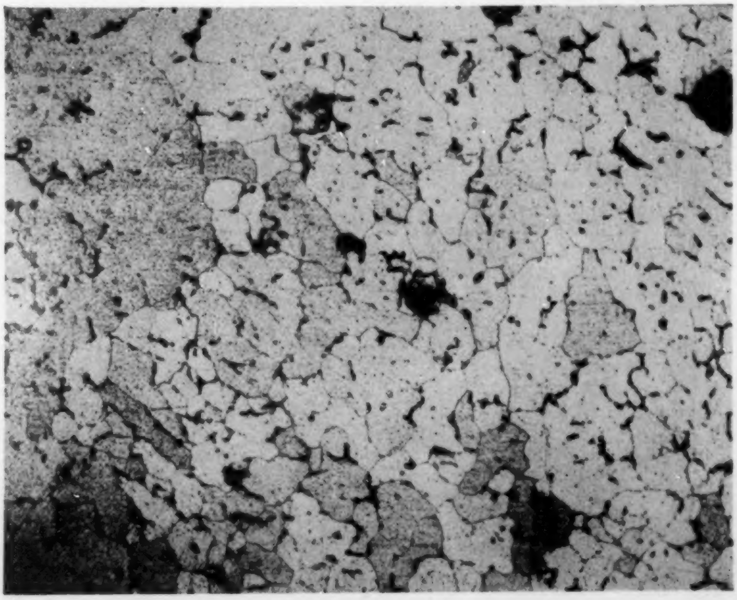


FIG. 2—STRUCTURE OF WELD IN A 4 PER CENT COPPER, 96 PER CENT ALUMINUM ALLOY. ETCHED WITH KELLER'S ETCH. MAGNIFICATION, x75.

FIG. 3—A DEFECT IN AN ALUMINUM ALLOY CASTING.

9. To insure uniformity of composition, all the bars of each alloy were poured from the same heat. The alloy designations[1] and a typical analysis of each is given in Table 1.

Table 1

ALLOY DESIGNATIONS AND TYPICAL ANALYSES OF ALLOYS USED

Alloy No. 1	Per cent Alloying Elements Copper	Iron	Silicon	Zinc	Manganese	Magnesium	Nickel	Remainder
43	0.016	0.45	5.22	—	0.01	0.02	—	Al
355	1.31	0.47	5.17	—	0.02	0.53	—	Al
195	4.36	0.63	0.69	—	—	0.01	—	Al

WELDING PROCEDURE

10. The welding procedure used followed as closely as possible

1 Superior numbers refer to references at end of paper.

that recommended by the Aluminum Company of America[2].

11. The test bars to be welded were cleaned with a wire brush to remove all traces of cutting tallow left by the band saw used to notch the bars. After cleaning, each bar was marked with a piece of carpenter's chalk, placed on a gas heated grill, and preheated until the chalk mark turned white. The color change in the chalk occurs between 600 and 700°F. When the color change in a chalk mark became apparent, the welder removed the piece from the grill and immediately made the weld. During the deposition of the weld metal, the molten pool was well fluxed and puddled.

12. The procedure for welding the castings was the same as that used in welding the test bars, except that the surfaces were prepared by melting away the sides of the defects with the torch.

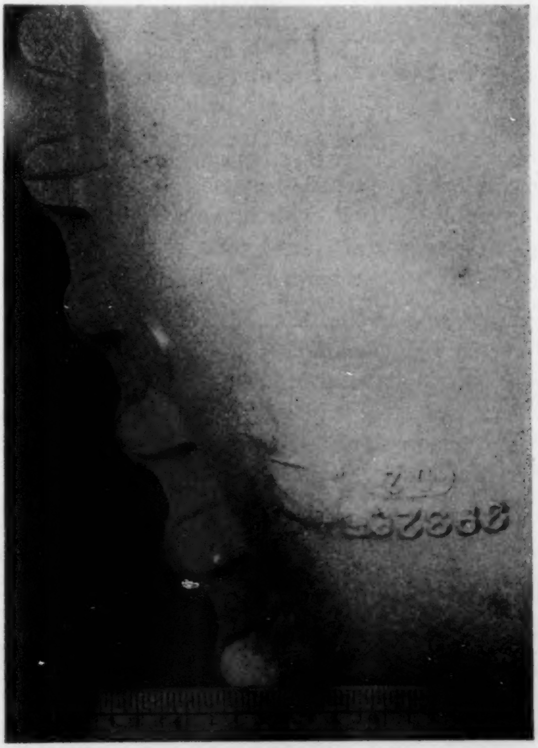


FIG. 4—SAME CASTING AS SHOWN IN FIG. 3 AFTER WELDING AND SAND BLASTING.

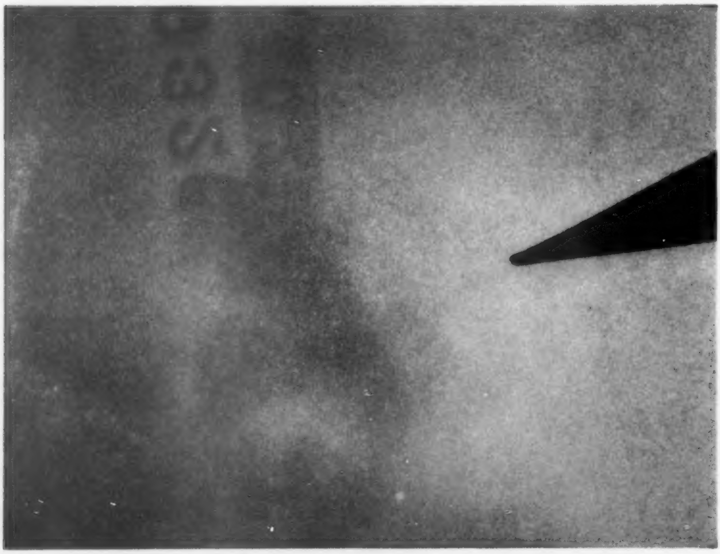


FIG. 5—RADIOGRAPH OF WELD SHOWN IN FIG. 4.

DATA AND DISCUSSION

13. The results of the tensile tests on the No. 43 alloy specimens are shown in Table 2. It is evident from the tensile data that the welded test bars are so nearly as strong as the "as-cast" bars that the difference can be disregarded.

14. In an attempt to find the reason for the excellent physical properties of the welded No. 43 alloy, sections were cut through the welds of several bars and polished for microscopic examination. In every case, the weld metal was found to be much finer grained than the parent metal. Figure 1 is typical of the structure found in welded No. 43 alloy.

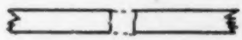
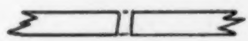
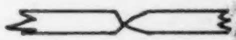
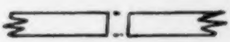
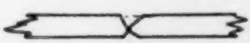
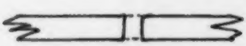
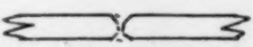
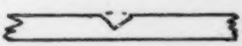
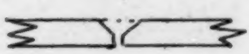
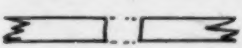
15. An explanation of the finer grained structure of the weld metal is found by a consideration of the welding process and of the casting characteristics of the 5 per cent silicon alloy. Welding is actually a casting process in which the sides of the piece or pieces to be joined form the mold. The thermal conductivity of the metal forming the mold is high, and the weld metal is rapidly chilled as it is deposited. It will be remembered that No. 43 alloy has a relatively narrow melting range and a comparatively high fluidity. These characteristics enable the weld metal to fill the

Table 2

ALLOY 43 AS-CAST TEST BARS—MACHINED

Specimen Number	*Tensile Strength, lb. per sq. in.*	*Elongation, per cent in 2-in.*
7	16,410	3.5*
10	15,840	3.5
17	17,250	4.0
23	17,300	3.5
25	17,350	4.0
27	16,800	3.5
29	17,300	3.5
30	18,050	4.0
31	17,830	4.0
32	16,800	4.0
Average	17,090	3.85

ALLOY 43 WELDED BARS—MACHINED

Specimen Number	*Tensile Strength, lb. per sq. in.*	*Elongation, per cent in 2-in.*	*Welds*
1	16,230	4.0	
3	16,745	3.5	
4	16,580	2.5	
8	16,720	4.0	
12	16,800	4.0	
14	17,260	4.5	
16	17,200	4.0	
18	16,900	4.5	
19	17,650	4.5	
20	19,415	4.0	
21	17,360	5.0	
22	16,230	4.0	
28	15,960	3.5	
Average	17,000	4.0	

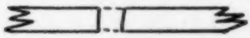
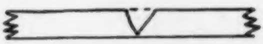
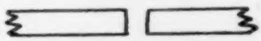
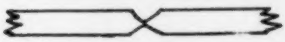
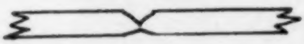
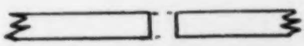
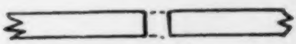
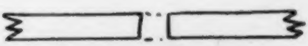
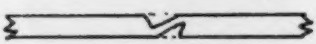
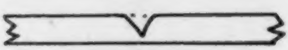
* Defect at Fracture.

FIG. 6—SAND HOLES IN AN ALUMINUM ALLOY CASTING.

FIG. 7—CASTING SHOWN IN FIG. 6 WITH SAND HOLE REPAIRED BY WELDING.

Table 3

HEAT TREATED ALLOY 355 TEST BARS—MACHINED

Specimen Number	*Tensile Strength, lb. per sq. in.*	*Elongation, per cent in 2-in.*	*Welds*
H-1	26,900	1.2	
H-2	36,485	1.5	NOT WELDED
H-3	33,650	1.5	NOT WELDED
H-4	34,115	1.2	
H-5	29,350	1.1	
H-6	35,685	1.5	NOT WELDED
H-7	28,495	1.0	
H-8	38,930	2.0	NOT WELDED
H-9	35,060	1.4	
H-10	30,200	1.0	
H-11	31,300	1.3	
H-12	26,930	X	
H-13	32,860	1.2	
H-14	35,170	1.5	
H-15	36,180	2.0	

Average:

As-Cast—36,185 lb. per sq. in. tensile strength and 1.8 per cent elongation.

Welded—31,320 lb. per sq. in. tensile strength and 1.3 per cent elongation.

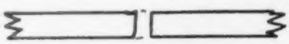
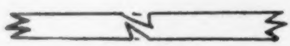
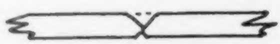
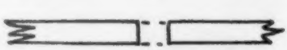
X—Broke in Fillet.

"mold" completely and freeze rapidly. In this way, the inherent characteristics of the metal combine with the welding process to produce the fine grained structure illustrated in Fig. 1.

16. The tensile data for Alloy 355 bars is shown in Table 3. It will be observed that the average strength of the welded specimens is slightly over 88 per cent of that of the "as-cast" pieces. This average value is lowered somewhat by the low results obtained on bars H1 and H12. H1 was defective in the weld area whereas H12

Table 4

HEAT TREATED ALLOY 195 TEST BARS—MACHINED

Specimen Number	*Tensile Strength, lb. per sq. in.*	*Elongation, per cent in 2-in.*	*Welds*
2	28,600	4.5	
3	24,500	1.5	
7	26,600	1.5	
11	26,800	3.0	
12	26,400	1.5	
1	30,000	3.0	
4	27,700	4.5	
8	28,100	3.0	
9	26,700	3.0	
5	33,200	4.5	NOT WELDED
6	33,700	4.5	NOT WELDED
10	34,300	4.5	NOT WELDED
14	33,900	4.5	NOT WELDED

Average:

As-Cast—33,275 lb. per sq. in. tensile strength and 4.5 per cent elongation.

Welded—27,265 lb. per sq. in. tensile strength and 2.3 per cent elongation.

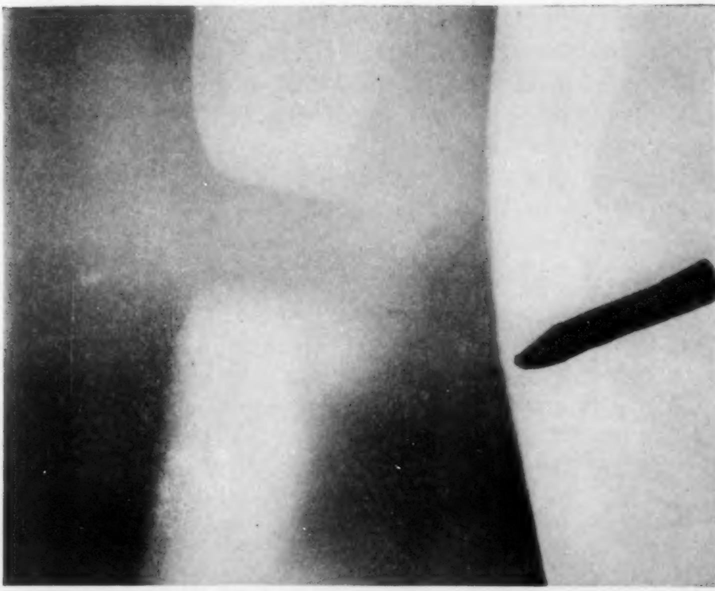


FIG. 8—RADIOGRAPH OF WELDED CASTING SHOWN IN FIG. 7.

broke in the fillet. The x-ray film showed defective welds in bars H1, H10, and H12. However, these defects are not revealed in prints due to loss of detail in printing.

17. Table 4 shows the physical properties of the welded and the unwelded Alloy 195 specimens. This group of test bars showed the greatest difference in the strength between the "as-cast" and

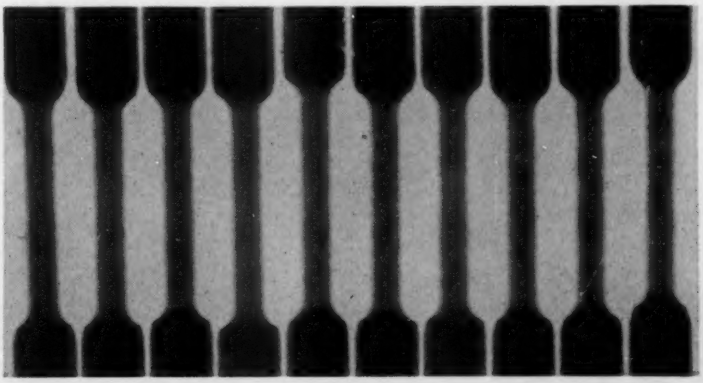


FIG. 9—RADIOGRAPH OF ALLOY 355 TEST BARS. FROM LEFT TO RIGHT, SPECIMENS NOS. H1 TO H10, IN ORDER.

the welded units, the average "loss" in strength amounting to 18 per cent.

18. Figure 2 shows the structure of a weld in Alloy 195. Here the difference in grain size between weld and parent metal is not so great as in the 5 per cent silicon alloy because the Alloy 195 contains very little silicon, which apparently acts as a grain growth inhibitor. The black irregular spots in the photomicrograph are porous areas.

19. Figure 3 shows a portion of a rough Alloy 43 casting containing a mis-run. Figure 4 shows the same casting after the defect had been welded shut, and the casting sand blasted. A radiograph of the welded casting is shown in Fig. 5.

20. Figure 6 shows two small sand holes in an Alloy 43 car-

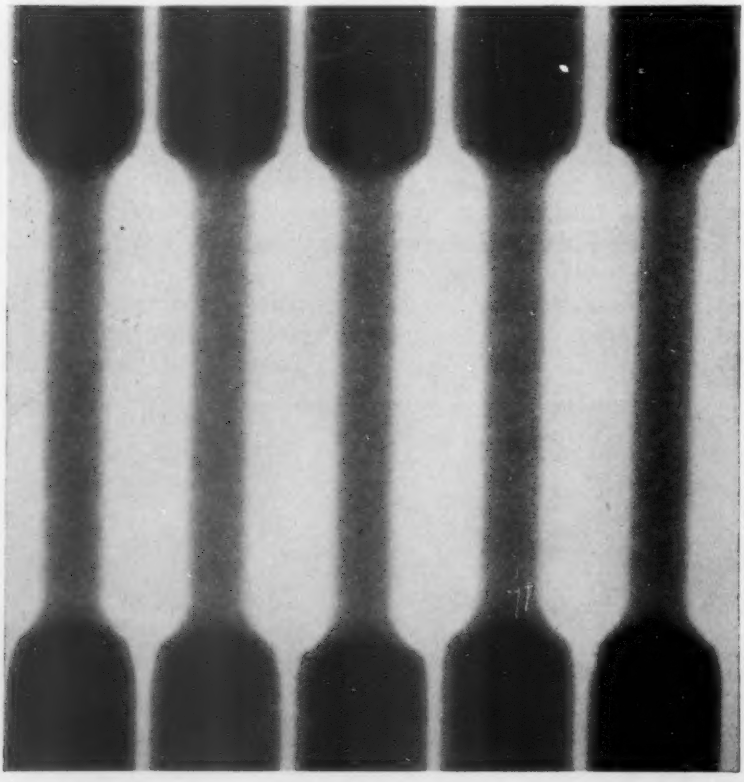


FIG. 10—RADIOGRAPH OF ALLOY 355 TEST BARS. FROM LEFT TO RIGHT, SPECIMENS NOS. H11 TO H15 IN ORDER.

buretor casting. While such defects do not structurally weaken the casting, they are sufficient grounds for rejection of the unit. Figure 7 shows the same casting with the sand holes welded over, and Fig. 8 is a radiograph of the weld.

SUMMARY AND CONCLUSIONS

21. It is possible to repair defects in No. 43 aluminum alloy sand castings and to secure, in the welded region, physical properties equivalent to those of the parent metal.

22. Castings of Alloys 355 and 195 also can be repaired by welding, but a slight loss in strength is to be expected, even if the castings are heat treated after the welding operation.

23. All castings repaired by welding should be radiographically inspected to insure sound welds.

ACKNOWLEDGMENT

24. The writers wish to express their appreciation to F. T. McGuire, formerly foundry metallurgist, Products Division, Bendix Aviation Corp., South Bend, Ind., for the data on the physical properties of welded, 5 per cent silicon alloys of aluminum.

REFERENCES

1. Aluminum Company of America Bulletin, "*Aluminum Casting Alloys*," p. 76.
2. Aluminum Company of America, "*Welding Aluminum and its Alloys*."
3. F. T. McGuire, "*Welding Aluminum Alloys*," unpublished report.

DISCUSSION

Presiding: W. J. LAIRD, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Co-Chairman: WM. ROMANOFF, H. Kramer & Co., Chicago.

D. L. LONGEUVILLE[1]: Do you use the same type welding rod as the original metal?

MR. RUPPE: Yes. We cast our own welding rods in the foundry and supply them to the welder.

MR. LONGEUVILLE: Are the castings pre-heated?

MR. RUPPE: All castings are pre-heated.

MEMBER: How about distortion?

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1 Wright Aeronautical Corp., Cincinnati, Ohio.

MR. RUPPE: Distortion is not a great problem with us.

MEMBER: Some of those castings appeared to be in the last stages of machining.

MR. RUPPE: That is correct, but even then, we had very little trouble with distortion and warpage.

JOHN MARDICK[2]: Do you heat-treat again after welding a heat-treated alloy?

MR. RUPPE: Yes. Ninety-five per cent of our work is with 43 aluminum.

MEMBER: I would like to add to what Mr. Ruppe has said by saying that welding has been in practice in the foundry for some time.

MR. RUPPE: The welding is conducted by the machine shop. The welders belong to the machine shop.

A. CRISTELLO[3]: When a casting has a defect, who decides as to whether it should be welded or not?

MR. RUPPE: All castings that require repair work are presented to a jury of three, who represent our Engineering Department, Plant Inspection and Customer Inspection. Those three individuals decide as to whether a casting is to be salvaged or not.

MR. CRISTELLO: I assume you are doing Army or Navy work. Where does the Navy or Army come in on the inspection of this?

MR. RUPPE: They are our customers.

MR. CRISTELLO: They do not object, do they?

MR. RUPPE: No.

MR. CRISTELLO: Do you find that your efficiency in the foundry or machine shop is very low?

MR. RUPPE: Six per cent of the total castings handled in the shop in the month of March were repaired by welding. The majority of these defects were caused purely through carelessness. A great number of the defects were caused by machine operators. One of the worst offenders seems to be stripped threads. With all the necessary handling of these castings it is easy to drop one and bang up a boss or corner. What are we going to do, throw them away? There may be $100 represented in one of these machined bodies. That's a lot of money.

H. J. ROAST[4]: I think that the company should be very much congratulated in having the backbone to admit they set out to accomplish this sort of salvage. Their success indicates the reasonableness of their attitude.

We in Canada have got to do things very much along those lines. We are no better foundrymen than you are, and so we have made castings that also are defective. We cannot get on with this war effort if we are going to stick to old regulations that are impracticable.

I speak in connection with English specifications going back to the days when they cast guns in bronze and then wound them with wire. Those specifications, in our country, are still pertaining in many cases. Something must be done along these lines and I think this company and

[2] American Magnesium Corp., Fairfield, Conn.
[3] Bendix Aviation Corp., Bendix, N. J.
[4] Canadian Bronze Co., Ltd., Montreal, P. Q., Canada.

this representative should be heartily congratulated. I hope that others here and in our country will follow in their footsteps to get good castings—everybody wants them good—but good castings salvaged in a proper way.

M. V. HEALEY[5]: I wish to concur with the authors' findings on the fact that, welding in 955 aluminum-silicon alloy, we have been able to at least equal the properties of the original casting and sometimes even to better it.

CHAIRMAN LAIRD: In the welded physical properties, you stated that the physical properties of the weld in the 5 per cent silicon alloy were equal to or greater than the parent metal on many occasions, while with the other two alloys they were less.

MR. RUPPE: About 80 per cent.

CHAIRMAN LAIRD: Is that due to the fact they are heat-treated?

MR. RUPPE: No, I think it is the alloy itself. I think the 5 per cent silicon alloy has better castability. I think you can do a better weld job.

CHAIRMAN LAIRD: The conventional welding rod is the 5 per cent silicon, of course.

MR. RUPPE: No, we use the parent metal. For instance, on 195 we make a 195 weld rod; and on the 355, we make a 355 weld rod.

D. V. LUDWIG[6]: Do you think that the difference in the materials in welding might be due to burning-out some of the alloy constituents, particularly the magnesium?

MR. RUPPE: We did not check the 195 and 355 alloys because we were not nearly so interested as we were in the 43 results.

MR. JUROFF: Mr. Chairman, if I might add a few words on the weldability of 195 and 355 alloys, the 195 especially seems to be more difficult to weld. The 195 has a considerably wider melting range and it seems to pick up more gas. The micrographs usually show small pores scattered throughout the weld metal, although the fusion is good.

MR. LUDWIG: I may be a little out of line on this but I do know that on one occasion in salvaging magnesium castings, welding was resorted to and it seemed to be successful. That was on a magnesium casting, a special job where somebody had designed the pattern incorrectly and left off the boss. So they put the boss on and it worked all right.

MR. RUPPE: Has anyone here done any experimenting with welding rod? We find it a hard job keeping the welders satisfied with rods. The rods are never any good. The welder never makes a bad weld—it's always the fault of the rod. It doesn't seem to make any difference whether the rod is cast in "green" or "dry" sand or in a permanent mold; the rod is still no good.

MEMBER: We do quite a bit of work in 40-E, not heat-treated, and we have had examples of blow holes, as all foundries do. We have used both our own 40-E rod and the Aluminum Company's rod. We did not know the composition of the rod. We have been able to weld sections slightly less than ⅛-in. thick and get good, solid welds that will stand up under hydraulic pressures of 3,000 lb. per sq. in. and they show no trace

[5] General Electric Co., Schenectady, N. Y.
[6] Capitol Foundry, Inc., Astoria, L. I., N. Y.

of cross-sectional differences under the X-ray. I think it is a very wise thing to do and it is certainly possible to build up sections even as thin as 1/16-in.

CHAIRMAN LAIRD: It has been our experience in attempting to weld the heat-treated alloys, the 195 and 355, in which case we attempted to use the as-cast rod, that we had the same experience as you have had. The welder claimed the material was no good but by subsequently rolling the cast rod and increasing its density, we were able to improve it. Our experience checks with yours, so far as we know that we make the best weld with a 5 per cent silicon rod on the 5 per cent silicon material. It is my impression that the 80 per cent approach to the normal physical properties in the weld on the heat-treated alloys is due to the welding material rather than to the fact that it is subsequently heat-treated.

MR. LUDWIG: Did you find difficulty with blistering or gassing in the welding of 40-E?

MEMBER: No.

MR. LUDWIG: With the zinc?

MEMBER: That is done very close to the melting point. The surface is scraped and the welding rod is added. It is carried down to as low a temperature as we can possibly get the metal to flow.

MEMBER: On the welding of the flange for the copper adapter, were any tested in service?

MR. RUPPE: There are parts of the carburetor that we are not allowed to weld and the flange of the adapter is one of them.

MEMBER: I just wondered whether you have had any rejection of those?

MR. RUPPE: We have never had a service rejection on a welded casting in the past two years in which we have gradually built up our salvage procedure. I have just made a statement that I think is the crux of the whole matter of welding castings. I said that we were not allowed to weld parts of the carburetor. You can see we still have some selling to do. We've completely proved to ourselves that we can weld a metal equal to or superior to the parent metal. We know we can guarantee a clean, solid weld with proper fusion since we can inspect the weld with X-rays. However, the engineers, the inspectors, and the customers still refuse to let us weld in certain areas. Why? Evidently because we haven't fully convinced the boys that welding is a safe and sane means of repairing 43 aluminum alloy castings, no matter what the defect. You can rest assured that we'll do everything possible to eliminate the cause but will still put up an argument before we remelt a casting.

A Metallurgical Study of Cast Iron for Glass Forming Molds

By W. H. Bruckner*, Urbana, Ill., and Harry Czyzewski**, Peoria, Ill.

Abstract

The prime requisite for the working surface of the glass mold is that it polish highly and be free from imperfections. Thus far, cast iron has been used as the material for glass molds, and the authors have investigated the effect of structure on the life of glass molds. In the forepart of their paper, they discuss the microstructures of such molds and the causes for failure. They also point out the difficulties encountered in production due to the failure of such molds. Although cast iron has been used, the life of various molds varies considerably. To test the effect of the type iron and its treatment on glass mold failure, an accelerated cracking test was devised. The degree of cracking in the specimen after a given number of quenchings from 1100°F. indicated the relative resistance of the irons to heat checking. The various type irons and their treatments are recorded in the paper, together with results of the accelerated cracking tests.

1. Permanent metal molds came into use in the glass industry when cast iron was substituted for the previously used molds of wood and plaster. Modern, automatic machine methods of glass making require a large number of blank and finishing molds which are fixed to a rotating table operating at high speeds. The blank molds alternately receive the hot glass, the partially formed ware is discharged to a finishing mold, and the blank molds are cooled by an air blast or a water spray for the subsequent glass forming cycle. The finishing molds are put through a similar cycle and discharge

* Research Assistant Professor of Metallurgical Engineering, University of Illinois.
** Junior Engineer, Caterpillar Tractor Company.

Note: This paper was presented at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

to the conveyor which carries the ware to the annealing ovens.

2. In starting a glass forming machine, it is necessary to heat the molds externally with a gas burner, or other means, to the desired operating temperature of between 1250° and 1100°F. at the surface of the blank mold in contact with the glass. Lubrication of the mold, plungers and neck rings is practiced during glass-making, and consists of the application of a deposit of carbon from an acetylene flame or burning paraffin oil, etc., on the surface in contact with the glass. This surface is called the working surface in the remainder of the paper.

Requirements of Mold Surface

3. The present, wide-spread use of cast iron for mold material is indicative of satisfactory economic and technical factors in its use for glass-making. The prime requisite of the working surface of a glass mold is a highly polished surface which is free from imperfections. This demands the close grain and sound metal ob-

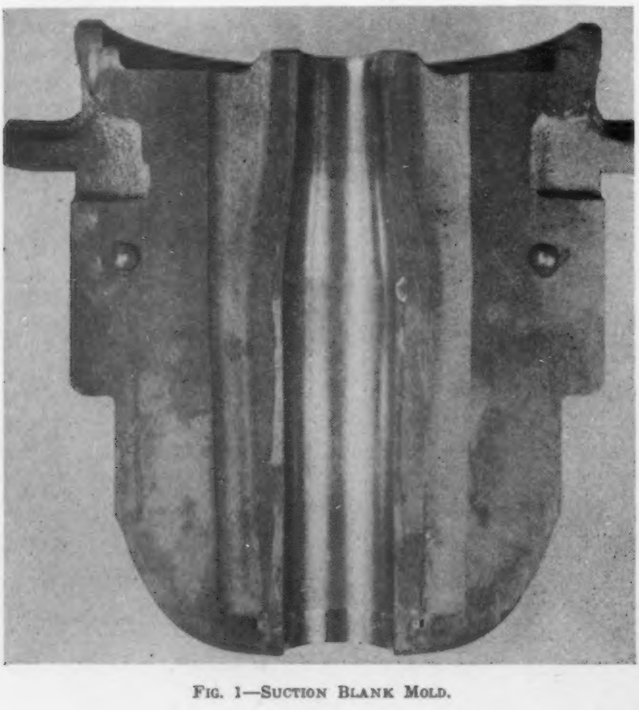

FIG. 1—SUCTION BLANK MOLD.

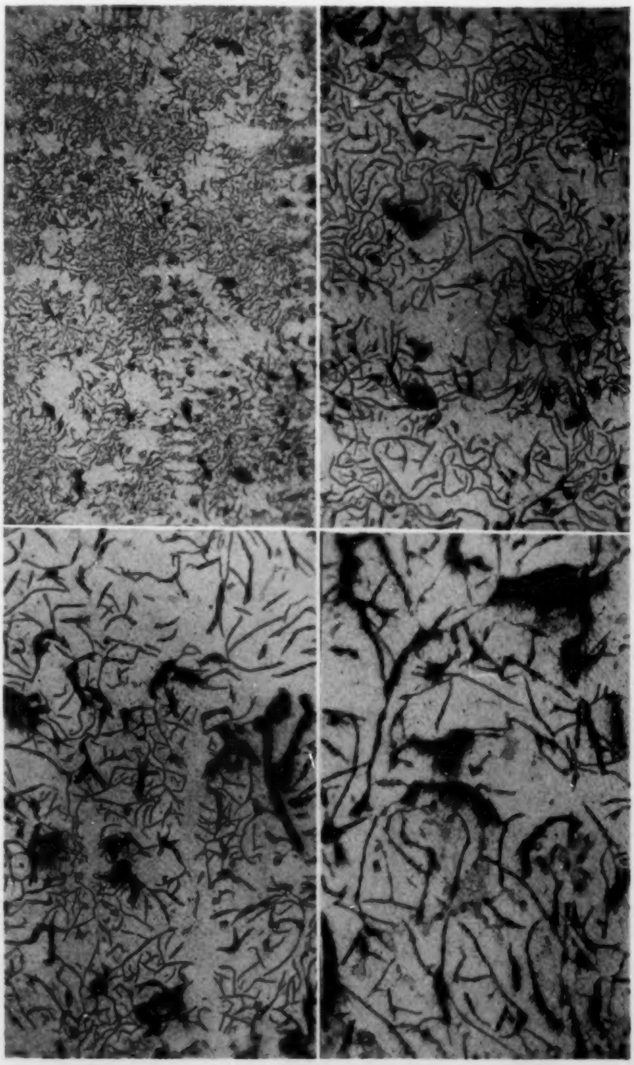

FIG. 2—TYPICAL MICROSTRUCTURES OF A CAST IRON MOLD. A (UPPER LEFT)—AT WORKING SURFACE. B (UPPER RIGHT)—AT 7.5 MM. BELOW WORKING SURFACE. C (LOWER LEFT)—AT 15 MM. BELOW WORKING SURFACE. D (LOWER RIGHT)—AT 26 MM. BELOW WORKING SURFACE. ALL ETCHED IN 5 PER CENT NITAL, MAGNIFICATION, x75.

tainable by casting against a chill. Another important requirement is that of easy machinability, since many of the molds must be shaped by hand to the desired contour. To obtain a high degree of

machinability in the chill and to produce a graphite-ferrite-pearlite structure, it is usual for the mold iron to have a high silicon content.

4. Fig. 1 shows one half of a blank mold used in the suction process of filling the mold with glass. In this process, the blank molds skim the surface of the glass tank and the glass is sucked into the molds, the excess glass at the bottom of the mold is sheared off and falls back into the tank.

Microstructures of Mold

5. Figs. 2 and 3 show the gradient in the microstructure resulting from the action of the chill. The distances from the working surface of the mold are indicated and it can be noted that a widely dispersed condition of fine graphite in a rosette pattern exists at the surface. The size of the graphite, and the pearlite content, increase away from the chill. At the surface, pearlite is entirely absent but in *E*, Fig. 3, it constitutes about 10 per cent of the area of the micrograph. This is the usual structure of the gradient in a chilled mold iron, which would have a composition in

FIG. 3—TYPICAL MICROSTRUCTURE OF CAST IRON MOLD AT 37 MM. BELOW WORKING SURFACE. ETCHED IN 5 PER CENT NITAL, MAGNIFICATION, x75.

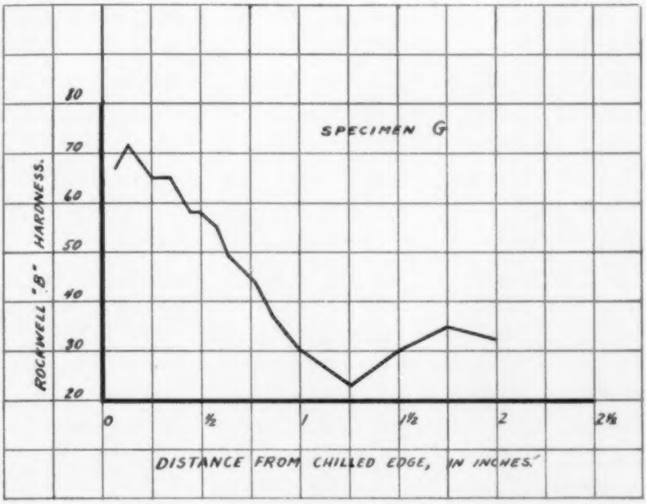

FIG. 4—HARDNESS GRADIENT OF GLASS MOLD.

the range of 3.65-3.75 per cent total carbon, 2.0-2.75 per cent silicon, 0.5-0.6 per cent manganese, 0.1 per cent sulphur, and 0.2-0.3 per cent phosphorus. The hardness gradient across the chill to the sand cast side of the mold is shown in Fig. 4. The decrease in hardness is attributed to the increasing size of the graphite and porosity. The maximum hardness at the working surface is sufficiently low to provide excellent machinability.

Failures

6. Service failure of glass molds is usually due to cracking, which starts at the working surface and progresses into the body of the mold in a direction normal to the working surface. The practice of the glass house is to sand blast the working surface of the mold periodically to remove the scale and expose the cracks that have formed. If the mold cannot be cleaned up with a high polish, free from cracks, it usually is discarded. An example of a mold which was run for a longer than usual period is shown in Fig. 5. The network of deep cracks on the working face can readily be seen. The more usual cracking, which is sufficient to require that the mold be discarded, is shown in Fig. 6.

Results of Mold Failure on Operation

7. The necessity for discarding the cast iron glass-forming

blank molds used in the suction process is reported by the glass industry to occur at any time between the production of 200 to 50,000 gross of glassware. Occasionally several molds in a large shipment will fail at a low grossage while the remainder are satisfactory. However, in the event of unsatisfactory glassware due to roughness resulting from a cracked mold, the glass-forming machine must be stopped while the faulty mold is replaced, and the new mold is heated to the operating temperature.

8. The inconsistent service life of molds, and their occasional rapid failure, promotes dissatisfaction in the glass industry with the use of cast iron for the molds. A study of the metallurgical factors which influence the service life of glass molds was considered to be the first step in answering the problem presented by the glass industry to the foundry. To do this required the cooperation of the glass house to supply molds for a study of the cracking phenomenon, and of the foundry to supply cast irons whose susceptibility to crack formation could be evaluated and related to metallurgical factors.

MATERIALS

9. A number of glass-forming molds were obtained from the

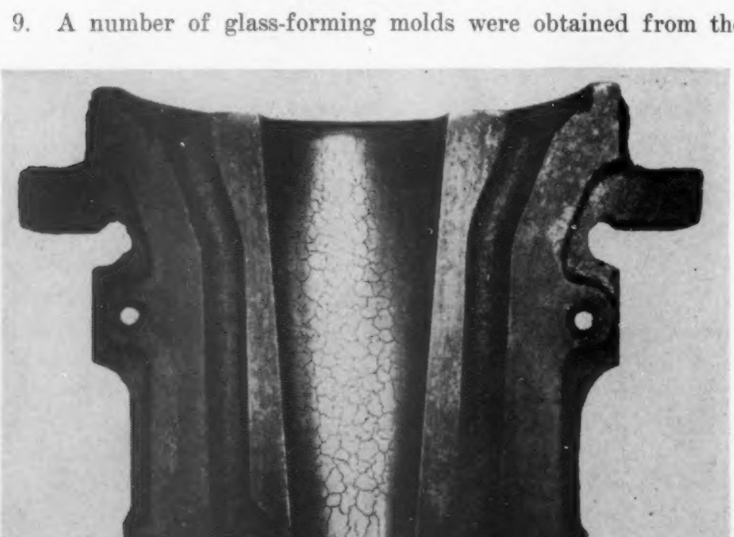

FIG. 5—SUCTION BLANK MOLD SHOWING NETWORK OF WELL-DEVELOPED HEAT CHECKS.

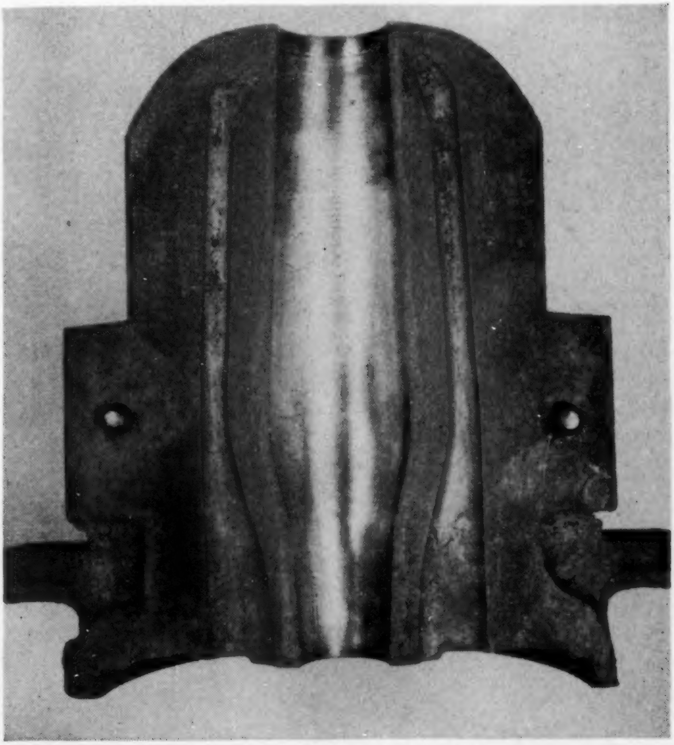

FIG. 6—SUCTION BLANK MOLD WHICH HAS BEEN DISCARDED, DUE TO CRACKING.

glass industry. Some of the molds had given excellent service while others failed by cracking after a short service period. All of the molds that were of interest were sectioned and examined to determine the paths of the cracks, and the microstructure.

10. The first application of an accelerated cracking test, to be described later, was made on bars of low and high strength gray cast iron which were cast in a sand mold. The chemical composition of these bars is shown in Table 1. On completion of the tests on the low and high strength iron, a series of cast blocks was obtained in the compositions shown in the lower part of Table 1. The blocks of cast iron with the compositions shown were 6x9x2½-in., in size; the SA1, SA2, and SA3 irons were sand cast, and the irons designated CA1, CA2, and CA3 correspond in chemical composition with the SA series, but were cast with one 6x9-in. face against a metal chill.

11. The irons of the T series, TF, TP1, and TP2, were also cast with one 6x9-in. face against a metal chill. They represent plain irons of different pearlitic content, increasing in the order given. The chiller used for the blocks of iron in series "T" and "C" was a cast iron block of the same size as those supplied for test specimens. This method of casting provided the same type of gradient from chill-cast to sand-cast surface as exists in the actual glass-forming mold.

PROCEDURE

12. A laboratory test was devised which would produce cracking of test specimens in a shorter time than when the cast iron was used as a glass mold. It was found that a simple procedure of heating specimens of cast iron to 1100°F. and quenching in water at room temperature produced cracks similar in nature to those observed in the examination of glass molds. The specimens to be cycled in this manner were lathe turned from the sand cast bars of low and high strength iron to 2-in. diameter and cut to 2-in. in length. They were then given a high polish all over and tested. Periodic descaling, after every 10 cycles, was practiced to visually observe the extent of cracking which was obscured by the presence of scale. These tests were continued to 40 cycles. Similar tests were made on smaller cylinders 1-in. in diameter and 1-in. long to determine the effect of mass on the severity of cracking.

13. When these preliminary tests had established the success of

Table 1

CHEMICAL COMPOSITION OF CAST IRON TEST BARS

	Composition, Percent							
	Total Carbon	*Silicon*	*Manganese*	*Phosphorus*	*Sulphur*	*Nickel*	*Chromium*	*Molybdenum*
Sand Cast Bars 1.2-in. and 2-in. Diameter								
Low Strength	3.56	2.25	0.59	0.45	—	—	—	—
High Strength	3.11	1.75	0.51	0.225	0.10	1.25	0.60	—
Sand Cast Blocks, 6x9x2½-in.								
SA1	3.39	2.23	0.68	—	—	1.25	0.45	0.50
SA2	3.57	1.50	0.68	—	—	1.20-1.50	—	0.20-0.30
SA3	3.50	2.02	0.65	—	—	—	—	0.35-0.45
Chill Cast Blocks, 6x9x2½-in.								
CA1	3.44	2.40	0.66	—	—	1.25	0.45	0.50
CA2	3.57	1.50	0.68	—	—	1.20-1.50	—	0.20-0.30
CA3	3.50	2.00	0.80	—	—	—	—	0.35-0.45
TF	3.61	2.99	0.67	—	—	—	—	—
TP1	3.55	2.76	0.66	—	—	—	—	—
TP2	3.60	2.50	0.66	—	—	—	—	—

the testing procedure in determining comparative susceptibilities to cracking, specimens were taken out of the cast blocks for similar tests. The specimens were again 2-in. in diameter and 2-in. long with a drilled and tapped hole in the center of one flat face for a threaded 1/4-in. rod, on which the specimens were suspended during the test. In the case of the chilled irons of series "C" and "T," one flat face of the cylinder was prepared by removing just enough material from the chill surface to give a smooth, highly polished surface, the other opposite flat face contained the threaded hole. The cylinders taken out of the sand-cast blocks of series "S" were similarly prepared. The specimens were then cycled in the cracking test, the chilled irons being subjected to a maximum of 20 cycles and the sand-cast irons to a maximum of 40 cycles.

14. To determine the effect of a modification of the microstructure, other specimens, which had previously been given the following heat treatments, were subjected to the cracking test:

1. *Anneal.*—Chill cast irons of series "T" and "C," brought slowly to 1450°F., held for 4 hours and furnace cooled.

2. *Spheroidize.*—Chill and sand cast irons heated slowly to 1280°F., held for 100 hours and furnace cooled.

3. *Quench and Draw.*—Chill cast irons of series "T" and "C," heated slowly to 1650°F., quenched in oil, reheated to 1280°F., and furnace cooled.

15. At the conclusion of the cracking tests, a study was made of the microstructure and the type of cracking which occurred. Hardness tests also were made to determine the hardness gradient across the chill- and sand-cast region in the as-cast and as-heat-treated condition, and compared with the hardness gradient occurring in actual blank molds.

Discussion of Data

16. The low and high strength sand-cast bars, whose compositions are given in Table 1, had hardness values of 75 and 98 Rockwell "B" and tensile strengths of 20,500 and 54,000 lb. per sq. in., respectively. Their behavior in the cracking test can be stated as follows: After 10 cycles, the number of cracks observed in the high strength iron was slightly more than in the low strength iron. After 20, 30, and 40 cycles, the heat cracks in the specimens of low strength iron outnumbered those in the high strength iron.

The specimens of high strength iron had more severe cracks, being both deeper and wider than those in the low strength iron.

17. Parallel tests made with smaller cylinders of the low and high test iron 1-in. in diameter and 1-in. long, showed no cracking until after 10 cycles, and only a few cracks developed up to 20 cycles. At the end of 40 cycles, the relative severity of cracking of low strength and high strength iron was approximately the same as for the 2-in. diameter cylinders.

18. The small cylinders were more resistant than the large cylinders to the formation of heat-checks, apparently owing to the mass effect in intensifying cracking in the cylinders of larger mass. The benefits attainable in reducing the mass of material undergoing similar cycling in heating and cooling could be obtained by modification of the glass-mold design to prevent the use of excessively massive molds.

19. Table 2 gives the results of accelerated cracking tests carried out on specimens taken from the cast iron blocks, the compositions of which are shown in Table 1. For the as-cast, plain irons of series "T," the data are incomplete with respect to observations of the number of cycles undergone before the initiation of cracks.

Table 2

NUMBER OF CYCLES BEFORE CRACKING OCCURS

Specimen	*As Received*	*Annealed*	*Spheroidized*	*Maximum Pearlite*
TF		1-2	1-2	3
TP1		7-8	1-2	2
TP2		3-4	4	4
SA1	slight		fine	
SA2	cracking		cracks	
SA3	at 40		at 7-8	
CA1	8-9	22-23	5	8-9
CA2	5-6	5-6	1-2	5
CA3	4	6	1-2	2

However, the series "T" and "C" irons, in the as-cast condition, had approximately the same resistance at the start of cracking, but the alloy irons of series "C" were less severely cracked at the end of 20 cycles than were the plain irons of series "T." This comparison is made in Fig. 7, which reproduces the appearance of the chill-cast face of the as-cast specimens at the end of 20 cycles of heating and cooling.

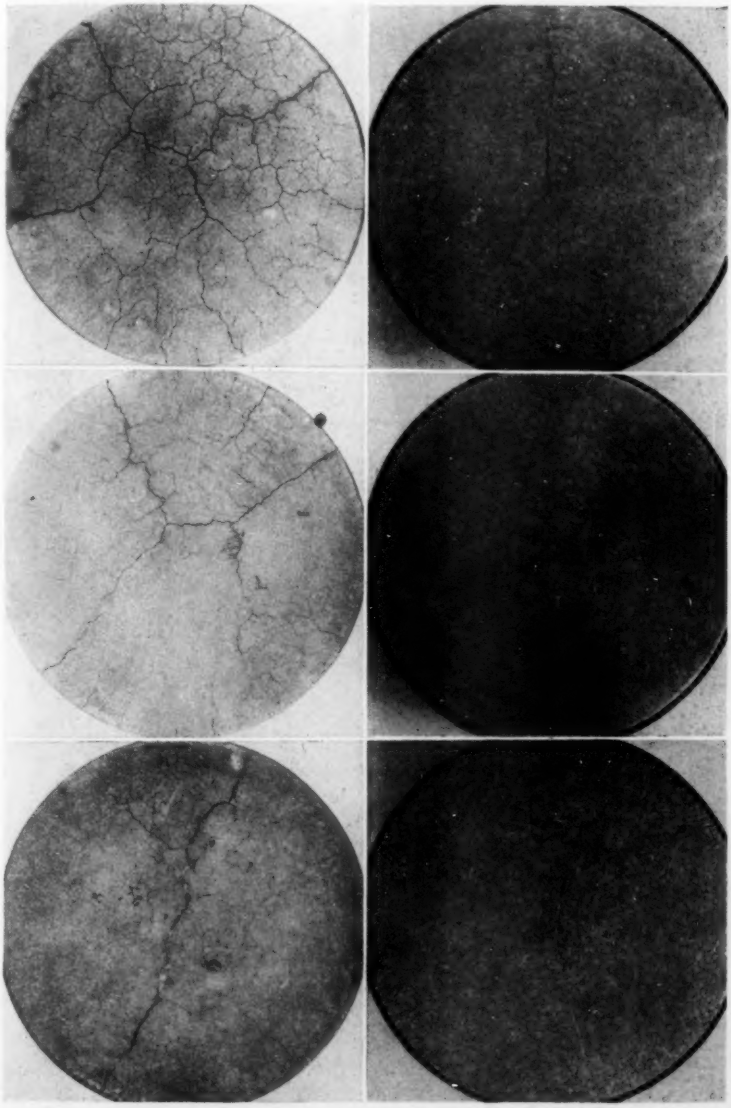

FIG. 7—APPEARANCE OF CHILL-CAST IRON SPECIMENS SUBJECTED TO ACCELERATED CRACKING TEST FOR 20 CYCLES. LEFT—TOP, TF; CENTER, TP1; BOTTOM, TP2. RIGHT—TOP, CA1; CENTER, CA2; BOTTOM, CA3.

20. The as-sand-cast irons of series "S" were the most resistant to cracking and were only superficially cracked at the end of 40 cycles. The cracks in the sand-cast irons were more numerous than in any other specimens and had a network appearance. The sand cast face of the specimens taken from the chill cast blocks had a similar high resistance to cracking.

21. The annealing heat-treatment was most effective in increasing the resistance to cracking of the CA1 iron, while the spheroidizing heat treatment in every case reduced the resistance to cracking below that of the as-cast irons. The quench and draw, designed to give maximum pearlite, appears to have been ineffective in modifying the resistance to cracking. This was an unexpected result, since the specimens were expected to have a higher resistance to cracking on the basis of the relief of casting stresses alone and especially on the basis of the fine pearlitic matrix of high strength, which was established by the quench and draw treatment.

MICROSTRUCTURES

22. The gradient in microstructure from the chill- to the sand-cast face of the cast iron blocks is represented by three regions shown for the CA1 iron in Fig. 8, where CA1A represents the chill area, CA1B, the middle of the 2½-in. thick block, and CA1C, the sand cast area of the block. The chill areas of all the alloy irons, CA1, CA2, and CA3, are shown in Fig. 9, and for the plain irons, TF, TP1, and TP2, in Fig. 13. It is evident in Fig. 9 that the prominence of the dendrites increases in the order of CA1, CA2, CA3, which is also the order of decreasing resistance to cracking, as indicated in Table 2. In Fig. 10, the plain irons have an increasingly dendritic appearance in the order of TF, TP1, TP2, which is the approximate order of increasing resistance to cracking.

23. It would appear from these data that the susceptibility to cracking in the plain cast irons may not be directly related to their dendritic structure. Observation of a large number of heat cracks in the cast iron specimens indicates, however, that the paths of the cracks are influenced by the dendrites as typified by the micrograph of Fig. 11 for such a crack in the CA1 specimen. The chill area is at the right, and the crack progresses from the chill to the interior from one graphite cluster to another, and along the dendrites.

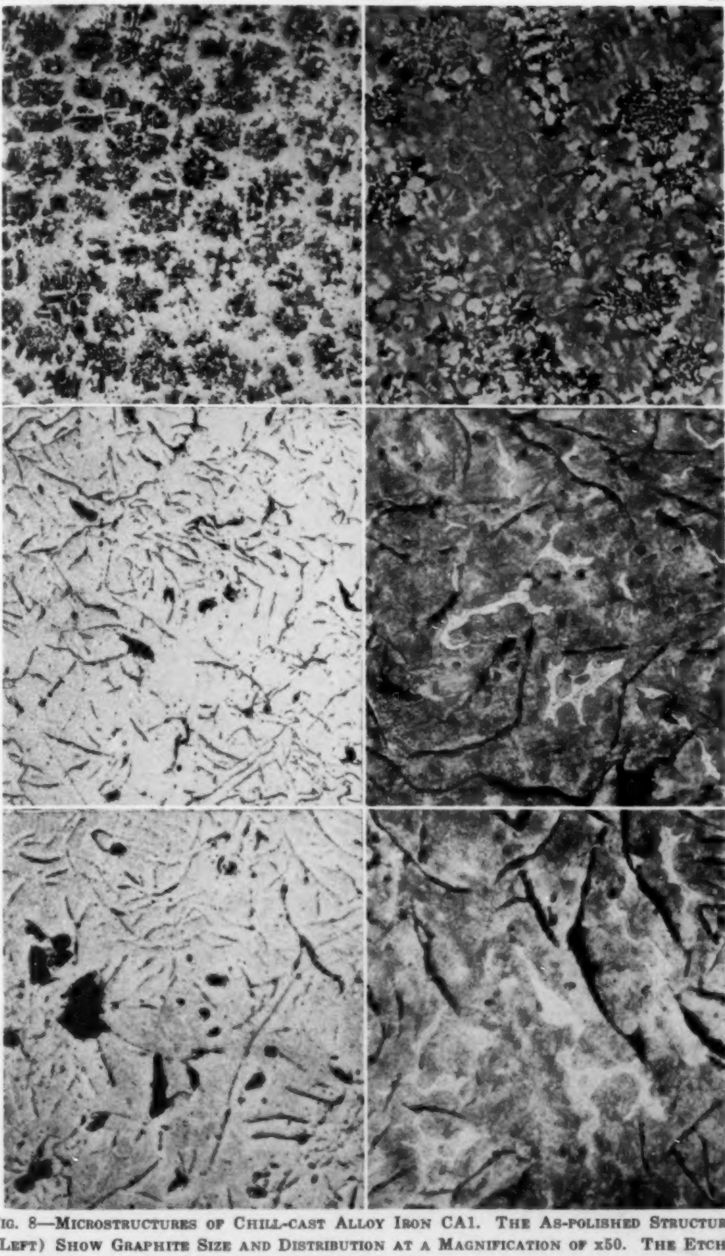

FIG. 8—MICROSTRUCTURES OF CHILL-CAST ALLOY IRON CA1. THE AS-POLISHED STRUCTURES (LEFT) SHOW GRAPHITE SIZE AND DISTRIBUTION AT A MAGNIFICATION OF x50. THE ETCHED STRUCTURES (RIGHT) SHOW DISTRIBUTION AND AMOUNT OF GRAPHITE, PEARLITE, FERRITE AND HIGH PHOSPHORUS AREA AT A MAGNIFICATION OF x150. TOP ROW—CA1A; CENTER ROW—CA1B; BOTTOM ROW—CA1C.

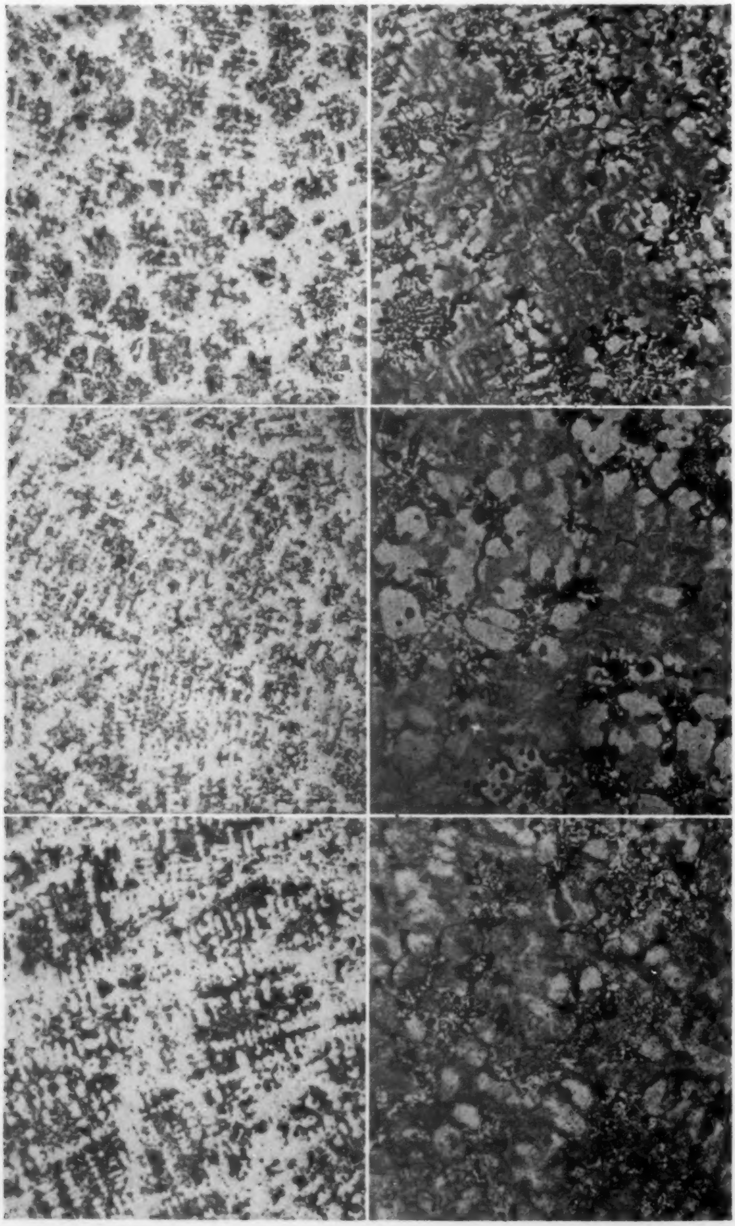

FIG. 9—MICROSTRUCTURES OF CHILL-CAST ALLOY IRONS CA1, CA2 AND CA3, IN THE CHILL AREA *A*. LEFT—AS-POLISHED, x50. RIGHT—ETCHED WITH 5 PERCENT NITAL, x150. TOP ROW—CA1A; CENTER ROW—CA2A; BOTTOM ROW—CA3A.

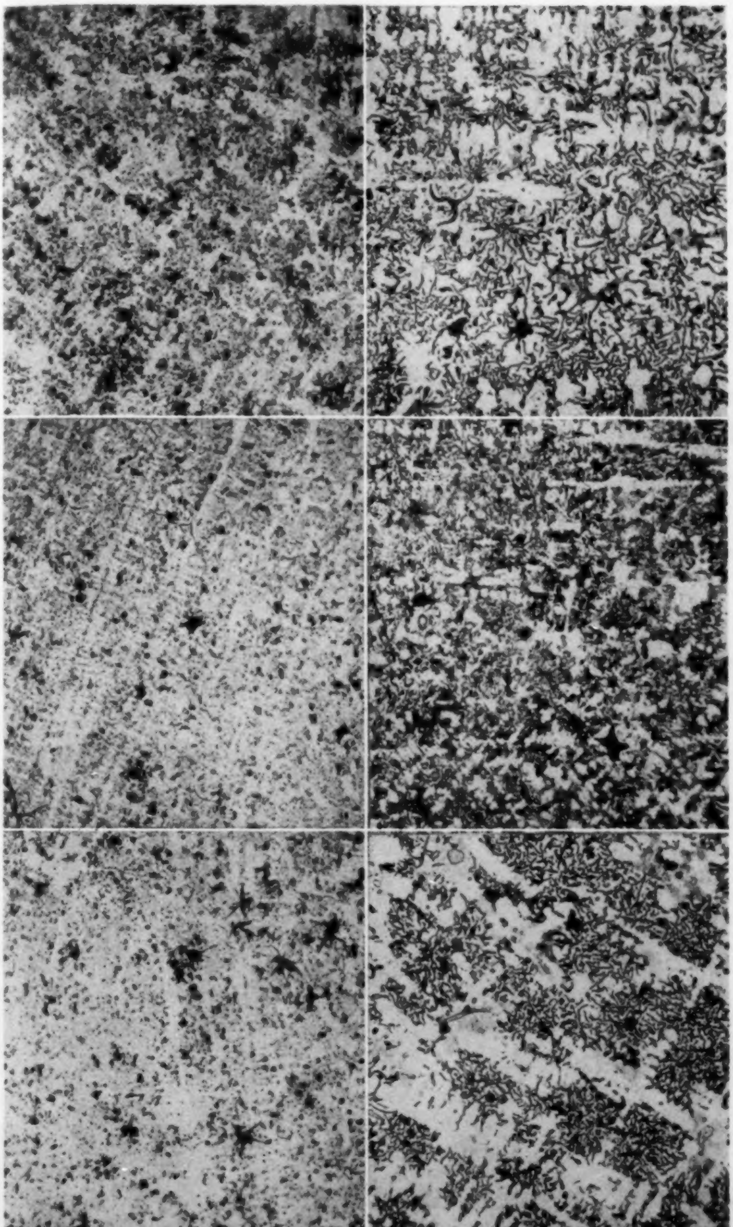

FIG. 10—MICROSTRUCTURES OF CHILL-CAST PLAIN IRONS TF, TP_1 AND TP_2 IN THE CHILL-AREA *A*. LEFT—AS-POLISHED, x50. RIGHT—ETCHED WITH 5 PERCENT NITAL, x150. TOP ROW—TF; CENTER ROW—TP1; BOTTOM ROW—TP2.

24. The sand cast irons, which were most resistant to heat cracking, are characteristically without evidence of a dendritic structure, and have large flakes of graphite, as indicated in Fig. 12 for the SA1 iron. The effects of the heat treatments given the irons before subjecting them to the accelerated cracking tests, may be followed in Fig. 13, which shows the microstructures of the CA1 iron chill region before and after heat treatment.

25. In the as-cast condition, the structure consists of lamellar pearlite, ferrite, and the usual rosette-graphite in the chill area. The anneal has partially spheroidized the pearlite, but the greater portion still remains lamellar; the partial spheroidization was probably occasioned by the slow cool from the annealing temperature. The spheroidizing heat treatment is shown to have quantitatively transformed the lamellar pearlite to spheroidal form, thus providing a totally ferritic matrix. The quench and draw is shown to have produced a fine pearlitic matrix with a minimum of free ferrite.

26. The lower resistance of the totally ferritic matrix, as compared with the pearlitic matrix, is believed to be due to the removal of the barrier to the advancing crack.

27. The lamellar pearlite represents a barrier, since its presence causes the deflection of the direction of the crack into ferritic or graphitic areas. The low resistance of the quenched and drawn iron, on this same basis, would appear anomalous, since it is almost totally pearlitic, and should have given a maximum resistance to cracking. The microstructure of the annealed iron is intermediate between that of the spheroidized and the quenched and drawn condition. Its high resistance to cracking is ascribed to the balance between lamellar pearlite and free ferrite which was attained. An examination of glass molds which had produced an unusually low grossage of ware before cracking, indicated that the pearlite in the chill and slowly cooled regions had been practically completely spheroidized. The degree of spheroidization precluded the possibility of it having occurred during the brief service life of the molds, thus it was considered to have occurred during an anneal prior to machining. In view of the results of the accelerated tests, it was concluded that the heat treatment of the molds did not provide them with maximum resistance to cracking.

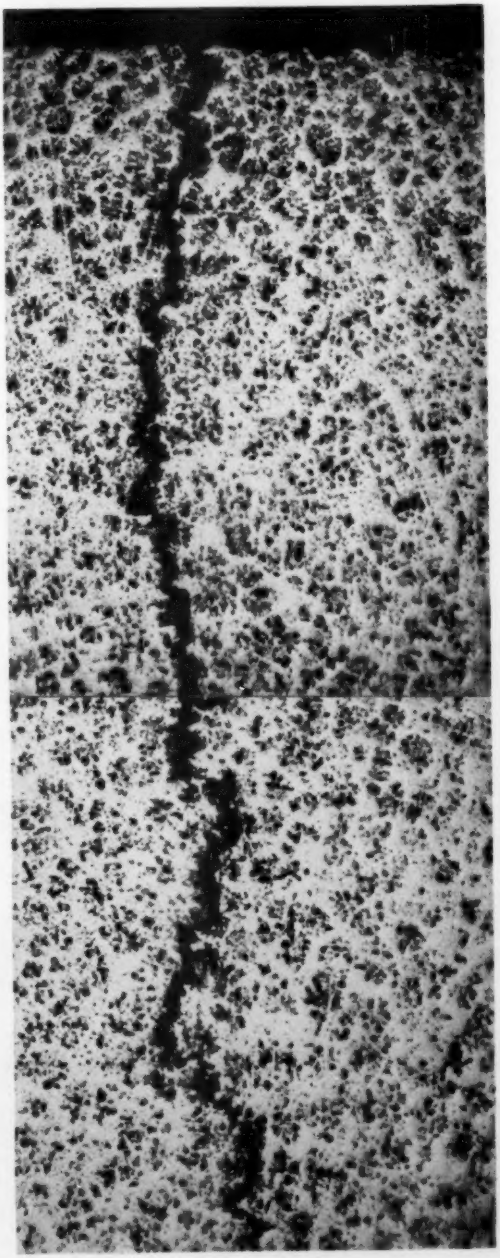

FIG. 11—PROGRESS OF CRACK THROUGH CHILL AREA OF SPECIMEN CA1.

HARDNESS GRADIENTS

28. Hardness surveys were made with the Rockwell "B" indenter on the chill- and sand-cast irons. These are shown for the alloy irons in Figs. 14 and 15. Similar hardness surveys were made on the heat treated specimens of the CA1 alloy iron and are shown in Fig. 15. The uniformity in hardness of the sand-cast iron across the 2½-in. thick block casting is indicated in Fig. 14. The hardness values decrease in the order of A1, A2, A3 for both the "C" and "S" series. The effect of the heat treatment on the hard-

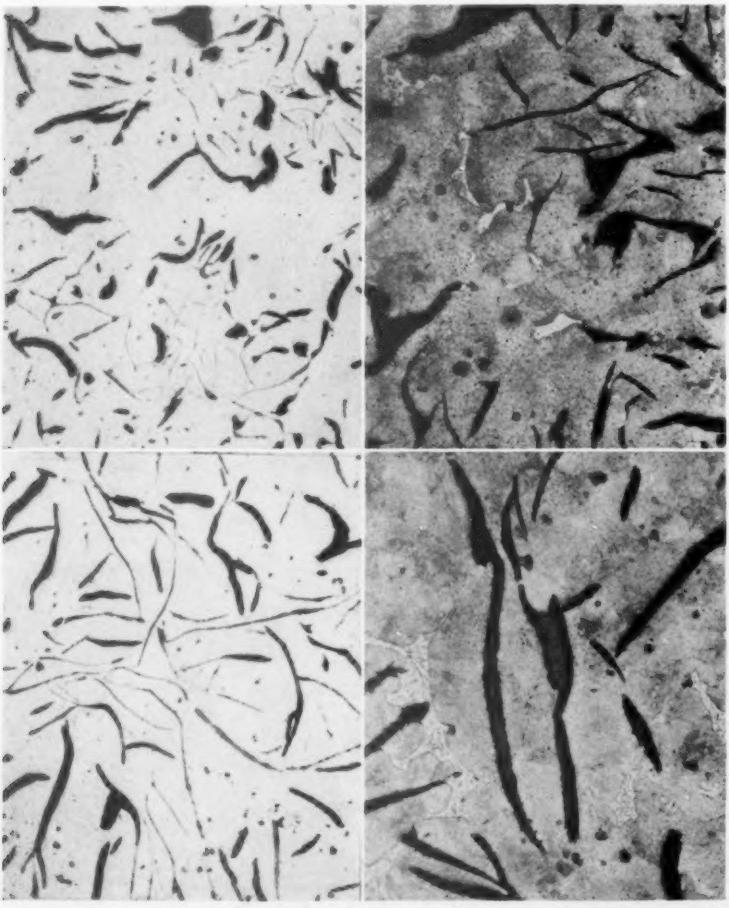

FIG. 12—MICROSTRUCTURES OF SAND-CAST ALLOY IRON SA1. LEFT—AS-POLISHED, x50. RIGHT—ETCHED WITH 5 PER CENT NITAL, x150. TOP ROW—SA1E; BOTTOM ROW—SA1C.

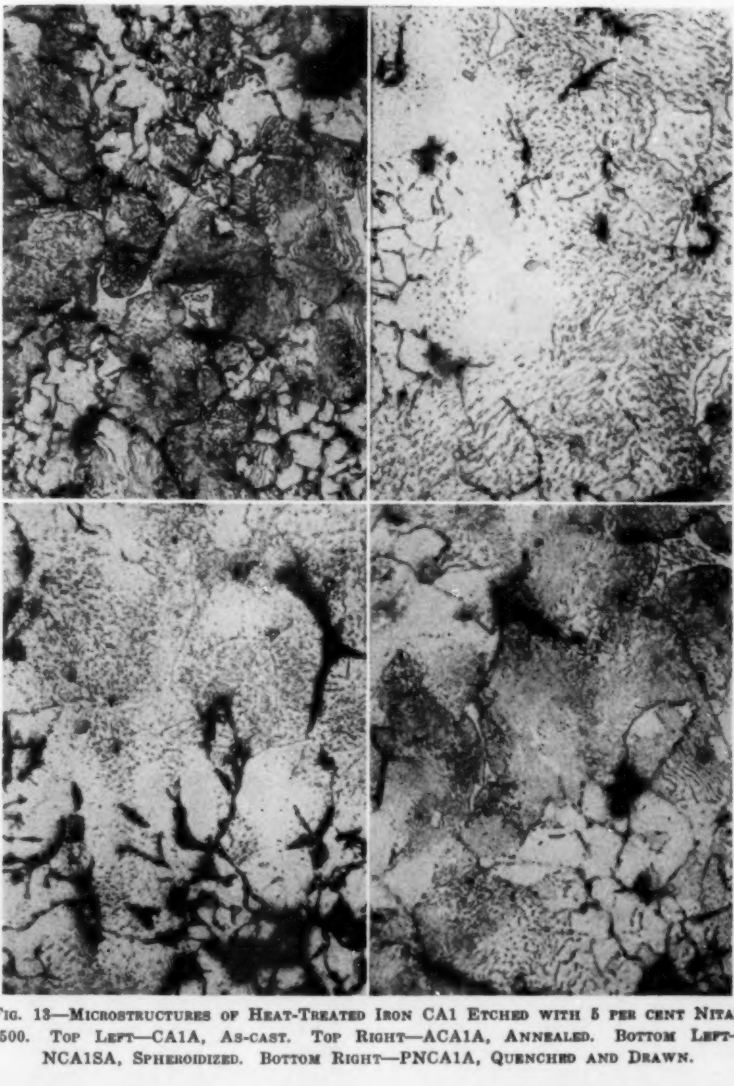

FIG. 13—MICROSTRUCTURES OF HEAT-TREATED IRON CA1 ETCHED WITH 5 PER CENT NITAL, x500. TOP LEFT—CA1A, AS-CAST. TOP RIGHT—ACA1A, ANNEALED. BOTTOM LEFT—NCA1SA, SPHEROIDIZED. BOTTOM RIGHT—PNCA1A, QUENCHED AND DRAWN.

ness gradients is shown, in Fig. 16, to have been least for the quench and draw given to specimen PNCA1. The hardness of the spheroidized specimen NCA1S is a minimum while that of the annealed iron ACA1 is intermediate between PNCA1 and NCAIS. A curve has been drawn below the hardness gradient for ACA1 to indicate the porous region in the slowly cooled portion of the cast-

ing where a considerable spread in hardness is encountered.

29. Table 3 gives the physical properties of the sand-cast bars of the same composition as the "T" and "C" series of irons which were cast at the same time as the block castings. These values are no indication of the properties of the chill portion of the chill-cast blocks but serve as a guide to show the effect of varying the chemical composition. The tests were made by the Gunite Foundries Corp., Rockford, Ill., which supplied the data for Table 3. For the alloy series, the CA1 iron, having the maximum resistance to cracking, had a lower modulus and ultimate strength than either CA2 or CA3. CA1 also had the maximum hardness of the alloy series. There is, however, no consistent relation between resistance to cracking and physical properties for the CA1, CA2, and CA3 irons or for the "T" series.

SUMMARY AND CONCLUSIONS

30. Cast iron of the composition studied, when cast in a sand mold, is most resistant to cracking during the alternate heating and cooling of the accelerated cracking test. The advantages of such an iron which contribute to the high resistance are the lack of a definitely dendritic structure, and the uniformity of the microstructure and physical properties over the cross section of the casting. The microstructure of the as-sand-cast irons consists mainly of coarse graphite, lamellar pearlite, and varying amounts of ferrite. The lamellar pearlite contributes to the high resistance

Table 3

PHYSICAL PROPERTIES OF CAST IRON SAMPLES

Specimen	*Transverse Strength, lb., on 18-in. centers*	*Deflection, in.*	*Ultimate, lb. per sq. in.*	*S x d*	*Modulus of Rupture, lb. per sq. in.*
TF	1720	0.32	21500	538	4560
TP1	1750	0.33	20380	530	4630
TP2	1780	0.32	18600	556	4710
SA1	2830	0.28		1010	7500
CA1	2050	0.21	28800	977	5340
SA2					
CA2	3000	0.35	37200	857	7950
SA3	2350	0.27	29500	871	6220
CA3	2400	0.27	29400	888	6350

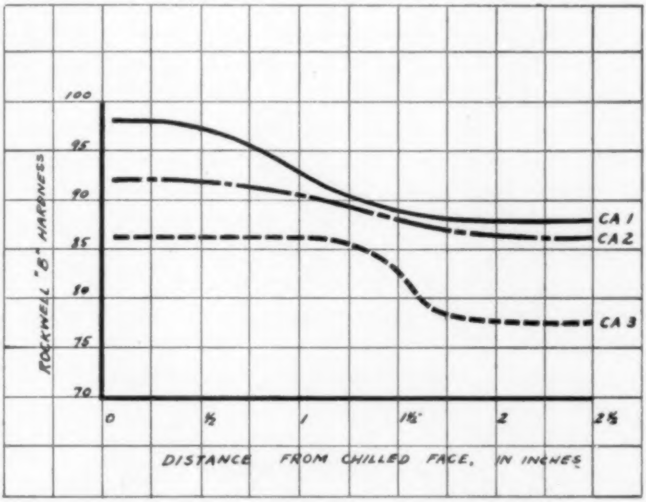

FIG. 14—HARDNESS GRADIENTS IN CHILL-CAST ALLOY IRONS.

to cracking, since a spheroidizing heat treatment, which transforms the lamellae to spheroidal form, reduces the resistance to cracking. The sand-cast irons, however, have an open, porous structure, and it is not possible to polish the surface to the degree required for the working surface of a glass forming mold.

31. Chill-cast irons, when subjected to the accelerated cracking test, show an early failure, and the cracks formed are relatively fewer and more severe than those formed in a sand-cast iron of the same composition. The severity of cracking in chill-cast alloy irons is less than in the case of the chill-cast plain irons, although the initial cracking in both irons takes place in approximately the same number of cycles. The use of the three metals, nickel, chromium, and molybdenum, as additions to the chill-cast iron, produces a superior product which is most resistant to cracking. The response of this chill-cast alloy iron to an annealing heat treatment is such as to give a greatly improved resistance to cracking.

32. The formation of an entirely ferritic matrix in the cast irons, by means of a spheroidizing heat treatment, reduces the resistance of the irons to cracking. The formation of a matrix of fine lamellar pearlite, by means of a quench and draw heat treatment, gives the chill-cast irons no increased resistance to cracking over that of the as-cast iron. Both the spheroidized and the

quenched and drawn iron had been stress relieved at 1280°F., and, therefore, represent the minimum and maximum strength of the matrix, respectively, under comparable conditions. The hardness of the annealed iron is intermediate between that of the iron in the spheroidized and the quenched and drawn condition. The microstructure of the annealed iron is also intermediate between that of the latter two irons. The matrix is composed of free ferrite, partially-spheroidized pearlite and lamellar pearlite, which apparently gives a desirable combination of ductibility in the ferrite for absorption of the thermal shock and high strength in the lameller pearlite to resist the spread of cracks. Accurate control of the annealing operation would, therefore, appear to be necessary to attain a balanced microstructure for maximum resistance of the glass mold to cracking in service.

ACKNOWLEDGMENTS

33. The data reported in this paper were obtained by senior students in Metallurgical Engineering who made part of the problem the subject of their senior thesis. Beside the junior author, now with the Caterpillar Tractor Co., Peoria, Ill., the seniors were Robert S. Hogue (National Carbon Co., Cleveland, Ohio) and L. R. Kovac (International Harvester Co., Chicago).

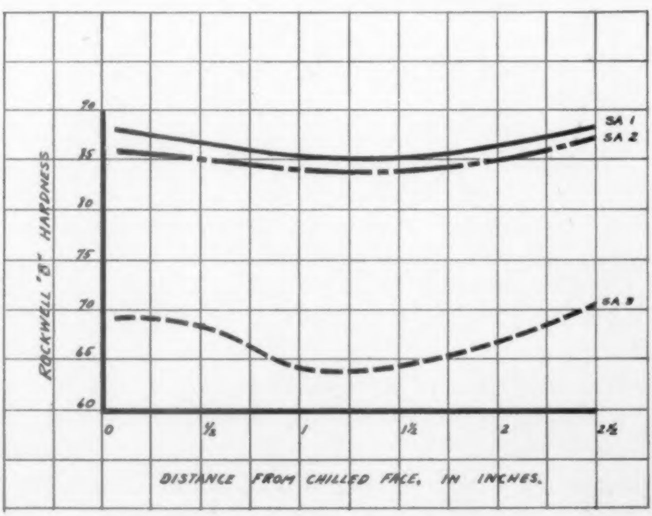

FIG. 15—HARDNESS GRADIENTS IN SAND-CAST ALLOY IRONS.

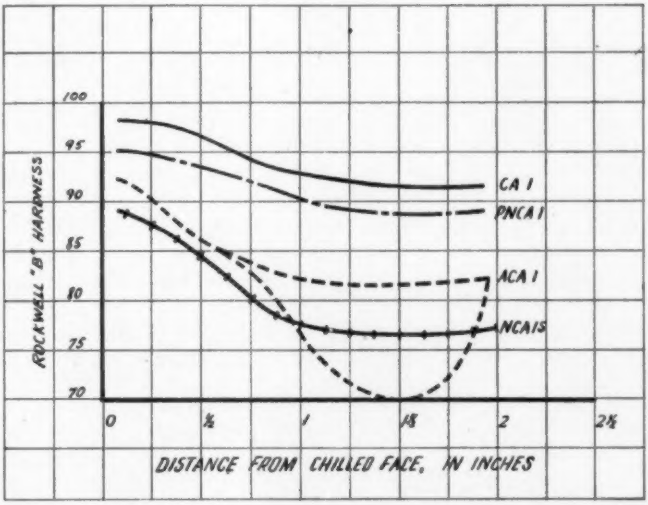

FIG. 16—HARDNESS GRADIENTS IN CHILL-CAST ALLOY IRON CA1 BEFORE AND AFTER HEAT TREATMENT.

34. Grateful acknowledgment is made of the helpful counsel and interest in the research given by Professor H. L. Walker, Acting Head, Department of Mining and Metallurgical Engineering. We also wish to acknowledge with thanks the kind permission to publish the data given by Dean M. L. Enger, Director, Engineering Experiment Station, University of Illinois.

35. The large supply of cast iron for test specimens was provided without charge by D. P. Forbes, President, Gunite Foundries Corp., Rockford, Ill. The generous supply of glass molds with different service histories was made possible by F. G. Passotti, Superintendent of Machine Shops, Ball Brothers Co., Muncie, Ind. The Thatcher Mfg. Co., Streator, Ill., also supplied several molds for examination. Interest in the research was expressed by The Overmyer Mold Co., The Piasa Foundry Co., The Sneath Glass Co. and others.

36. Professor C. W. Parmelee, Head, Department of Ceramic Engineering, University of Illinois, suggested the problem of improvement of glass forming molds through metallurgical studies in 1938, and has given continued interest, aid and encouragement throughout the progress of the research. The paper was originally presented at the Glass Conference on the University of Illinois campus under the auspices of Professor Parmelee's department.

Bibliography

1. Smith, R. D., "*Metallurgical Needs of the Glass Industry*," METALS AND ALLOYS, vol. 7, 1936.

2. Evans, N. L., Geacher, W., and Gurst, J. E., "*Cast Iron for the Manufacture of Glass Bottle Molds*," JOURNAL, Society of Glass Technologists, vol. 20, 1936.

3. "*Eight Hundred and Fifty Million Bottles for Beer*," FORTUNE, vol. 8, 1933.

4. Scafe, R. M., "*Glass Molds Present Many Problems*," THE FOUNDRY, vol. 68, 1940.

5. Langer, G. B., "*Mold Design and Machine Operation*," GLASS INDUSTRY, vol. 19, 1938.

6. Gehlhoff, G., "*Relations Between Physical Characteristics of Glasses and Their Working Properties on Machines*," JOURNAL, Society of Glass Technologists, vol. 12, 1928.

DISCUSSION

Presiding: S. C. MASSARI, Association of Manufacturers of Chilled Car Wheels, Chicago, Ill.

Co-Chairman: R. G. MCELWEE, Vanadium Corp. of America, Detroit, Mich.

J. S. Vanick[1] (*written discussion*): It is evident from an examination of this paper that the authors were confronted with the problem of studying the complex and elusive property of susceptibility to heat checking because, as they point out, this property in many cases determined the performance of the castings in service. Foundrymen who make these castings have long been familiar with the need to produce surfaces which will be easily machined and capable of taking a very high polish. This polished skin must be preserved to transmit its luster to the finished glassware.

The very requirements of glass mold castings present a collection of contradictions in physical properties. It is known, for example, that a moderately hardened iron will acquire a higher polish than an extremely soft iron. One means of achieving higher hardness is to produce a stronger iron with less graphite. However, this accentuates heat checking, as the authors point out. It is also known that strength is an unimportant property in the case of glass molds. Therefore, the problem of achieving a high polish in heat check resisting irons points toward the development of a high carbon, highly graphitic, moderately hardened and easily machinable iron.

Our laboratories have also expended considerable time on the heat checking problem, and have developed a technique for qualitatively distinguishing between various cast irons. Our results agree with those of the authors that, for similar base compositions, a sand cast iron is su-

[1] International Nickel Co., New York, N. Y. Data supplied by Mr. Vanick's associates, Messrs. J. T. Eash, K. A. DeLonge, A. P. Gagnebin and F. B. Rote, Research Lab., International Nickel Co., Bayonne, N. J.

perior to chill cast iron in resistance to heat checking. Chill cast irons invariably develop a dendritic graphite structure, so that in this respect they resemble uninoculated gray irons. However, inoculants are not especially effective in the very high carbon types of gray irons, but if such irons are chill cast then inoculation should prove beneficial. It might be worth the emphasis to point out that the chill cast irons referred to here are gray or graphitic right up to the surface of the chilled face. Chill cast irons with a white-iron (non-graphitic) skin, we find, are more susceptible to heat checking than their chill cast gray companions.

We can further agree with the authors that a low carbon iron is inferior to a high carbon type, and in some of our work these compositions have been tested for extremely wide carbon contents ranging from 2.0 per cent to 4.0 per cent. It would be preferable in the case of these irons to emphasize the relationship between their carbon or graphite contents rather than with their tensile strengths. For example, a cast iron containing 2.8 per cent carbon and no alloys might be made to develop a tensile strength of 40,000-50,000 lb. but a high carbon iron of 3.4-3.5 per cent carbon with the same tensile strength could be made to possess a more superior resistance to heat checking than its lower carbon, lower graphite companion of the same strength. Thus, by simply observing the graphite content of various cast irons our results would indicate that a white iron with no graphite is very easily heat checked. It would be followed by low carbon, low graphite, dendritic types of uninoculated irons which are improved by inoculation, and these in turn would be inferior to higher carbon types where the graphite prevailed in a normal flake pattern corresponding to the structures shown by the authors for their sand cast irons. These are further improved by correctly alloyed irons whose compositions are adjusted to possess a high degree of toughness when hot and a low dilation intensity for the temperature conditions imposed upon the working surfaces. Figure 17 shows the relative difference in degree of heat checking.

In paragraph 8 the authors mention the dissatisfaction which occasionally threatens cast iron molds. We have attempted to meet these cases with a casting grade of nickel which possesses a higher thermal conductivity and better oxidation resistance than cast iron. It machines easily, has a Brinell hardness under 140 and may be chill cast to obtain excellent surface. Glass molds cast from such alloys have given satisfactory performance but their relatively high cost has led toward the development of composite-metal molds with a cast iron back and working face of the cast nickel alloy. In making these molds a ½-in. nickel liner was first cast, the outer surface then prepared and the cast iron backing cast around it.

The thermal conductivity of cast iron is not affected to any important degree by small changes in composition, but a change to nickel nearly doubles the thermal conductivity, and the hot toughness of the material offers a further advantage in its resistance to heat checking.

The coefficient of expansion of nickel and cast iron are so nearly alike that the separate materials when cast into a bonded composite tend

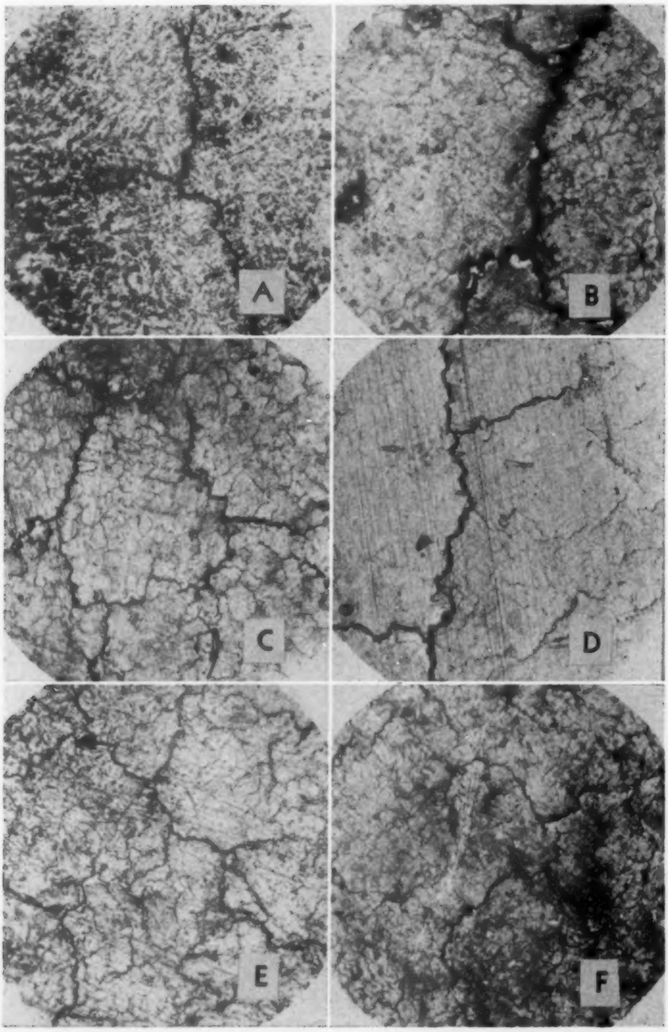

FIG. 17—RELATIVE DIFFERENCE IN HEAT CHECKED APPEARANCE AT x25 AFTER 10 CYCLES. A—CHILL CAST WHITE IRON. FAILED AFTER ONE HEATING. TOTAL CARBON, 3.15 PER CENT; SILICON, 0.90 PER CENT. B—SAND CAST, UNINOCULATED LOW CARBON IRON. TOTAL CARBON, 2.40 PER CENT; SILICON, 2.27 PER CENT. C—SAND CAST, INOCULATED LOW CARBON IRON. TOTAL CARBON, 2.40 PER CENT; SILICON, 2.27 PER CENT. D—SAND CAST, MODERATE CARBON IRON. TOTAL CARBON, 3.30 PER CENT; SILICON, 1.90 PER CENT. E—SAND CAST, LOW SILICON, NICKEL-CHROMIUM ALLOYED IRON. TOTAL CARBON, 3.30 PER CENT; SILICON, 1.37 PER CENT; NICKEL, 1.62 PER CENT; CHROMIUM, 0.61 PER CENT. F—SAND CAST, HIGH CARBON, NICKEL-MOLYBDENUM ALLOYED IRON. TOTAL CARBON, 3.65 PER CENT; SILICON, 1.28 PER CENT; NICKEL, 2.00 PER CENT; MOLYBDENUM 0.45 PER CENT.

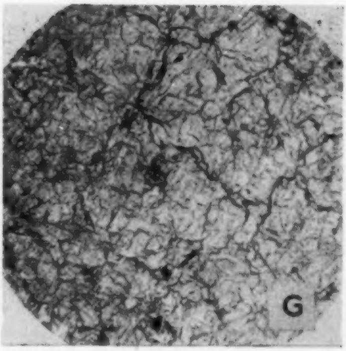

FIG. 17 (CONTINUED)—G—SAND CAST, HIGH CARBON, NICKEL-CHROMIUM-MOLYBDENUM ALLOYED IRON. TOTAL CARBON, 3.75 PER CENT; SILICON, 1.31 PER CENT; NICKEL, 2.00 PER CENT; CHROMIUM, 0.40 PER CENT; MOLYBDENUM, 0.35 PER CENT.

to retain their bond when subjected to temperature changes, and the combination will retain a thermal conductivity substantially higher than cast iron by itself, *viz.*:

	*Thermal Conductivity K**
Cast iron, 3.30 per cent total carbon—1.90 per cent silicon	0.110
Cast (C.G.**) nickel	0.200
½-in. Cast (C.G.**) nickel plus 1½-in. cast iron	0.158

R. D. SMITH[2] (*written discussion*): Many of the points brought out as a result of your investigation can be agreed with, particularly the findings in regard to the apparent superiority of unchilled iron in accelerated tests as contrasted with its actual unsuitability for reasons of poor mold and glass ware finish.

While the work apparently covers bottle mold iron and particularly "blank" or "parison" mold iron investigation, it is believed desirable that the reader should be cautioned in regard to the limitations of any accelerated test. It is very difficult to simulate the actual mold heating and cooling cycle. In press molds, for instance, the heating cycle differs markedly from that used in the accelerated test. The use of intimate hot glass contact with the mold surface followed by air or wind cooling, with water used only in internal cooling cavities of plungers, represents the press mold cycle as contrasted with furnace heating and water quenching in the accelerated test. Several suitable press mold compositions come to mind which would fail rapidly in the test outlined in the article under discussion.

Any accelerated test should be confirmed by having mold materials of known service life fail in the same order in the test and in service.

* K = $Cal/Cm^3/C^0$.
** C. G.—Casting Grade.
[2] Glass Technology Department, Corning Glass Works, Corning, N. Y.

With regard to the bibliography, it is recommended that the work of J. S. Vanick, "*Metallurgical Analysis of Glass Mold Cast Irons,*" THE GLASS INDUSTRY, July and August, 1938, be included.

CHAIRMAN MASSARI: There is just one thought I would like to inject here with regard to the question of thermal checking. Our desire to produce material ideally suited to resist thermal checking almost establishes an incompatibility. An iron resistant to thermal checking is one high in strength but likewise having a low modulus of elasticity. For a given temperature gradient, a lower stress level results within the casting in an iron having a low modulus of elasticity. Unfortunately, high strength irons are usually the ones of high modulus of elasticity as well. As a result, it is customary to use a relatively moderate strength and, hence, a rather low modulus of elasticity.

MR. VANICK: I would wish to classify these irons on the basis of their graphite content rather than high strength. I do not know whether you agree with that comment entirely, but in discussing Prof. Bruckner's paper the point was emphasized that in distinguishing between the high strength and low strength irons of Table 1, there is quite a difference in carbon content. It is possible to make a pretty strong iron of high graphite content with very low modulus.

CHAIRMAN MASSARI: I appreciate your point and it is well taken.

MR. BRUCKNER: From the work that we have done, I would say the aim should be for the lowest possible strength for these molds. The higher the strength goes, the more severe the cracking becomes.

CHAIRMAN MASSARI: I think that, however, is coincidental with high modulus of elasticity, Prof. Bruckner. Low modulus of elasticity in the face of high tensile strength results in a high factor of safety to resist the alternating stress due to the strains that are caused by the temperature gradients.

MR. BRUCKNER: We can speak of the elastic modulus of a bar or other specimen of uniform cross section but the modulus of the chill castings and the strength can be expected to vary along the gradient established by chill casting one face and sand casting the opposite face of the casting. That is why we have undertaken to test small bars along this gradient and establish the strength and modulus as a function of distance from the chill surface. The further data for the series of cast irons described in this paper will be available at some future date.

MR. MCELWEE: I want to confirm everything that Dr. Vanick has said. All our experiments on hot working dies and parts subjected to heat checking have indicated that we can run the total and the graphitic carbons high, and alloy to get what strength is necessary. We are not concerned too much about the strength of the casting. We are actually doing what you say, getting low modulus iron by running graphitic carbons very high. The only function of the alloy is to provide the necessary mechanical strength. Actually the high carbon iron does the job of producing low modulus iron beautifully.

R. L. BINNEY[3]: No member could be more appreciative of this interesting paper than we are. I have spent 30 years, almost exclusively, in this one field that deals with the coordination of the production of glass as related to the molds in which it is formed. Years in actual glass house work have taught us the mold problem from the glass producer's standpoint. For the past 20 years, we have devoted our metallurgical efforts almost exclusively to this field. We, therefore, feel we have sufficient background to appreciate this discussion, and to assist in the correct outlining of the problems involved.

The remarks by Mr. McElwee cover, in brief, the problem of heat cracking. For some years, we have selected only such irons as have a low modulus, as this is helpful in preventing heat shock cracks, which we think of as mass action cracking. The other type of cracking, which some call "checking," are small surface cracks, and develop on prolonged use. This form of cracking is different, and we consider it fatigue cracking. Here the ultimate strength probably plays a greater part than in the heat shock cracking. Both types of cracking are at least partially eliminated by selecting an iron of low modulus and adding alloy for strength.

This mold subject is quite complex, even though it is a small corner of the metallurgical field. The paper is admirable in that it has brought the matter to general attention. I think, however, the problem could have been attacked in a more comprehensive manner had the author stated at the outset more of the difficulties encountered, and then discussed each as a problem. It is well to point out that no one iron or alloy is a panacea for the many mold requirements. For this reason we have developed a series of both ferrous and non-ferrous alloys to meet varying conditions. To accomplish this the iron should possess the following characteristics:

(1) Be able to take a very fine polish free from surface defects.
(2) Resist the formation of scale.
(3) Resist cracking due to heat fatigue, heat shock and physical impact.
(4) Freedom from warpage and growth.
(5) Low coefficient of expansion.
(6) Correct heat conductivity.
(7) Resistance to abrasion.
(8) Sufficient malleability.
(9) Good machinability.
(10) Correct mechanical design.

These are not all the requirements that must be considered, as there are many special problems encountered that require much thought and experience before they can be correctly solved. We will mention some of the points involved applying to each of the above requisites.

Glass must have an acceptable surface. This is becoming more and more an important factor, hence the polish of the mold, which directly

[3] Binney Castings Co., Toledo, O.

affects this characteristic, must be excellent. Some irons will take a good polish, but will develop pitting in service. This is often due to the removal of the free graphite which the iron cannot retain because of expansion and contraction at the surface, and the sticking action of the glass. I suppose the majority of glass produced today is from 1800° to 2200°F. at the moment of contact, hence the surface of the mold is subjected to high temperatures. This causes expansion and contraction, rapidly developing flaws which have been polished over, and removes some free graphite. When we think of a satisfactory surface, we think of one that will operate a maximum amount of time. Upon this ability to maintain a good surface, depends in a large measure the value of the alloy. If the time is short, the mold must be removed and repaired, and this is an expensive operation. It requires slowing down or stopping of the machine, and interrupts the production. The plugging and peening costs can be a considerable item, and this destroys the detail cut in the mold.

Molds that scale readily require frequent cleaning. The formation of scale causes marking on the glass, and a foggy appearance develops as the scale gets heavy. This is one of the chief reasons for changing molds. Molds that can be run a long time where the surface is not important, develop scale to such an extent that the glass has a pitted appearance, and only in certain commercial work can this be tolerated.

Cracking has always been one of the most aggravating difficulties of the glass manufacturer, and has been one of our chief metallurgical problems. Cracking of a glass mold is not a simple matter, as the cracks may result from various causes. When glass at an average temperature of 2000°F. comes into intimate contact with the mold, the surface temperature of the mold rises rapidly, and there is a decided temperature gradient between the surface and the back of the mold. This intimate contact lasts but a few seconds when "wind," as the glass manufacturer says, is blown on the heated surface. This cycle of heat and cold sets up stresses and strains, and produces fatigue cracking at the surface. These cracks may go deeply into the casting as the length of time the mold operates increases. Most ware today where the marks cannot be completely eliminated by fire finishing is thrown out as rejects and the mold is discarded. When the gob or clot of glass drops into the mold, there may develop a heat shock failure or what we call mass cracking. Molds subjected to this sudden impinging of molten glass must be able to withstand this temperature shock. This type of cracking is much deeper and usually starts at some sharp point in figured molds. We frequently find only one type of cracking, but sometimes both. With proper alloys, you can avoid both for very long periods of time. Some molds open and close to eject the glass. On closing, partially set glass may come between the parts and physical strains and impact may cause cracking.

We do not regard highly the cracking test as discussed in the paper. We feel it does not cover the various types of cracking adequately. It is a useful test, but it would be better if coordinated with a test where heat and wind were alternately applied to the surface of the mold. We are

able to do this by having two jets play upon the surface, one a flame, and the other wind. This is not a perfect test, but does coordinate well with water shock tests, several of which we have developed.

Warpage and growth are dependent on the type of iron, and at times the design of the mold. In molds where the body is of more than one piece, the warpage is quickly noticeable along the edges and can be detected by the light showing through as the glass is being formed. After warpage starts, the molds are reshaped when cleaned, and sometimes the growth is arrested, but usually an iron showing this defect at the start is poor material, and should be discontinued.

The coefficient of expansion is a most important characteristic, especially when different irons are used for duplicate parts of the same mold. It is not unusual for the expansion of one part to be 0.002-in., while that of the other may be 0.004-in., and in cases like this, the proper closing of the mold is impossible. One can readily see the amount of trouble that results from the use of different irons in the same mold, and this often occurs. In designing a mold alloy, one of low coefficient is most desirable, and though the other characteristics may be excellent, an iron with a high expansion may completely ruin its usefulness.

The conductivity of the metal has a great deal to do with the rate of production. By varying the thickness of the mold, temperature can be controlled within restricted limits, but since the mechanical design can be changed but little, much dependence upon design is futile. Even in cases where the manufacturer is glad to change his mold design, operating conditions frequently interfere. This is one of the reasons why it is necessary to have a series of alloys to meet various conditions, for by employing alloys of different heat conductivities, it is possible to control the rate of production which is now an uppermost consideration. Molds that operate at very high speeds, producing large numbers of bottles or tumblers per minute, must be able to dissipate the heat. They must cool rapidly in order to maintain the correct temperature required for the high rate of production. When the molds do not cool rapidly the glass does not set, and the product is rejected. Opposite to this is the desire of hand shops for the retention of heat in the mold as many of them produce only four objects per minute, and the mold must remain hot while in service or a crizzled and defective product results.

Not only must the mold have the correct characteristics to withstand the high temperatures, but it must be able to resist wear from a purely abrasive point of view. Various glasses differ in their physical action toward the mold. Some are more abrasive than others, and tend to wear down the details of finely cut molds. All such failures are costly to the glass producer, as the machine work or die-sinking is expensive, and a mold must wear long in order to keep down the unit costs.

If the mold is sufficiently malleable, it may be peened where worn and considerable production still obtained. The great trouble here is that when certain alloying elements are used to resist scale and cracking, the peenability or malleability of the mold is often poor.

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Unfortunately, the machine shop has a great deal to say about the alloy selected, although this is not true today in some large modern

companies. Formerly, if a mold metal machined nicely and worked easily so that they could produce a bright shining mold in a minimum amount of time, the alloy was considered most desirable. For this reason many inferior materials got into the glass house only to produce headaches and losses as the chief recommendation was the way the metal machined. Even today, we find this condition prevalent where the machine shop has a voice in the selection of the metal.

As previously mentioned, the mechanical design of the mold has a great deal to do with its successful operation, but here many limiting conditions are imposed by the operating mechanisms which cannot be changed, so the complete revamping of molds from a mechanical standpoint is not to be attempted or given as an excuse for failure. The chemical and physical characteristics of glass are vital factors, and vary widely in different plants. These, in conjunction with the rate of production, produce problems which require much thought. They cannot be solved simply by producing an alloy that will withstand cracking.

Preheating of molds is an important factor. Some of the factories have regular preheating furnaces where the molds are brought up to temperature. In this way their resistance to cracking and shock is improved. Other plants heat their molds simply by dropping hot glass into them which is a severe test for the best of metals.

Molds are lubricated with various mixtures of oil and graphite, sulphur, wax, etc., and this adds another burden to the mold metallurgist. The action of free sulphur is well known, and is a detriment, although we have seen some of the finest molds swabbed with sulphur as the operators insisted it produced better glass and aided production.

Attempts have been made to impregnate the surface of the iron, and to plate it, as well as to use various lubricants, and a complete presentation of the subject should include a review of all of these efforts.

Until now, the discussions of the analyses of glass molds have been inaccurate and more a matter of opinion than of scientific research. For example, consider just one element. One metallurgist claims that 0.06 per cent combined carbon gives best results, while another insists that 0.60 per cent combined carbon is the optimum for the same molds. We have read various discussions in the literature which, while acting as helpful forerunners of correct knowledge, are to be taken with a grain of salt.

We do not believe this mold question can be attacked without first stating the problem more completely. The present paper has not done this, and we believe it would be helpful if it were developed from more angles than those presented. After many years, we realize that there are more phases to this work than appear on the surface, and much good research must be done before final sets of specifications can be made. We have never found even a series of iron alloys to completely cover the requirements, and have been forced into many years of metallurgical research on the non-ferrous alloys as a supplement to the irons.

We feel the paper is a stimulating introduction to what may, at some future date, be developed into a more complete analysis of this interesting subject.

MESSRS. BRUCKNER and CZYZEWSKI (*authors' closure*): It is gratifying to have the greater part of the comments made by the discussers in a complimentary vein. It is especially significant that support for the data obtained comes from a wider experience in the service behavior of cast irons than our own.

We appreciate Mr. Vanick's observations on the apparent correlation of graphite content and resistance to thermal checking. The further observation of Mr. McElwee to the effect that the higher graphite content reduces the elastic modulus is interesting, if actually the case. We regret that substantiating data are not at hand. One effect of increasing carbon content has been noted in the literature* as a decrease in the coefficient of expansion almost linearly with carbon content. Such reduction in thermal expansion would be as effective as a lower elastic modulus in reducing the stress level. The paper referred to further notes a decrease in the coefficient with up to 1 per cent nickel, 2 per cent copper, 8 per cent aluminum, and up to 0.5 per cent chromium in the cast iron composition.

The question brought up by Mr. Massari is answered by both Mr. Vanick and Mr. McElwee in that control of the elastic modulus of the iron can apparently be achieved with high carbon content. However, Mr. Massari has the same problem in control of a gradient in the manufacture of the chilled iron car wheels as we had in the chill casting for the glass-forming mold. Subject to experimental verification we can expect a variation in properties, with position in the chill gradient, of the cast iron mold and the chill iron car wheel. At present it is not known how the elastic modulus and strength vary with distance from the chilled surface nor how effective in reducing strength and modulus is an increase in temperature to the testing temperature of 1100°F., and to the highest temperature reached by glass molds in service. Mr. Vanick's comments with respect to graphite content were aimed at explaining the difference in resistance to thermal checking of our low and high strength sand-cast bars. Mr. McElwee also presumably referred to sand-cast irons for hot working dies and parts. Whether the simple expedient of increasing carbon content will provide greater resistance to thermal checking of chill-cast irons remains to be seen. We will certainly include a series of chilled irons having a wide variation in carbon alone for our future studies.

The alternate heating and cooling presents a fatigue problem in which the elastic modulus and temperature differential determine the stress level. The manner in which the stress is distributed and the disposition of the weakest portions of the internal structure of the iron will determine the rapidity with which a local check will propagate into a major crack. An increase in graphite content in a chill casting would not eliminate dendrites, thus the directional weakness along the graphite clusters making up the cores of the dendrites would still be present. The formula for the ideal situation which Mr. Massari reached for verbally is low modulus of elasticity to provide a low stress intensity for a

* Sohnchen and Bornhofen, ARCHIV FÜR DAS EISENHÜTTENWESEN, vol. 8, 1934, p. 357.

given temperature differential, adequate strength which will not be exceeded by the stress level to which the iron is brought by the maximum temperature differential to which it is subjected. Furthermore, the iron should be chilled to furnish the surface required for glass forming and should have, above all, excellent machinability but should contain no dendrites. Obviously this charts the region of the impossible toward which further research can aim.

Mr. Binney's discussion is concerned with the actual conditions which exist in the glass house where the cast iron molds are put to use. His discussion would indicate his preference for the word "abuse" as the last word in the previous sentence. We have seen the operators of these glass-making machines swabbing the working face of the molds with powdered sulfur and rubbing out hot spots with sticks of red rubber and felt almost as Mr. Binney about the apparent abuse of the cast iron. However, the records of from 15,000 to 50,000 gross of ware produced from good molds subjected to this type of service are proof that the foundries can meet the glass industry's specifications on occasion, if not consistently.

Regarding Mr. Binney's criticism of inadequate statement of requirements of molds, we thought that we had stated the two major requirements of (1) surface perfection, and (2) machinability which applied to any glass mold, irrespective of the glass-making process or machine. For our observation of service failures, the most severe condition encountered in glass making was chosen, *i.e.*, the blank mold operating on the suction process. Any progress in developing more resistant irons for this service could be applied to meeting the requirements of molds subjected to less severe conditions in other glass-forming processes.

Mr. Binney says that he determines the resistance of his cast iron to thermal checking by cooling the hot casting in water. We therefore consider it unnecessary to apologize for the test which we have established for accelerating the study of the thermal checking of cast irons. We have found in testing certain materials that we can obtain practically complete insensitivity to cracking in the drastic cooling to which the specimens are subjected. We have been able to evaluate the relative resistance of different irons by means of the test and full information regarding the temperature differentials during cooling and heating has been obtained experimentally. The test is therefore not as crude as it appears. For detecting small differences in susceptibility to thermal checking less drastic cooling would appear to be essential and will be applied in further studies of the more resistant irons culled from the many tested as described in the paper. The next step in more fully satisfying the demands of the glass industry is the service testing of actual glass-forming molds cast in the composition and given heat treatments as prescribed by the research for optimum properties. Such tests have been carried out currently by F. W. Dixon, Jr., of the Gunite Foundries Corporation, and it is our belief that his reports, when available for publication, will furnish an interesting and valuable chapter in the history of improvement of cast iron for glass-forming molds.

Dr. Smith's comments indicate that in the various methods of forming

glass there is a considerable difference in the thermal cycle undergone by the cast iron mold. He and Mr. Binney urge the same caution in interpreting the results of the accelerated test in terms of service life on different glass-making machines. We have exercised this caution in planning to have such service tests made after the accelerated test had been used to weed out the less resistant irons. With respect to the press mold cycle it is of interest to note that it is usual for a large flat tray mold (press mold), for example, to fail by local checking just under the region where the hot glass is delivered to the machine. The rest of the mold would be in fair shape when it is discarded due to severe cracking in the central region as noted above. Here the failure may be intensified by the non-uniform heating as contrasted with the possibly higher temperature of a blank suction mold but more uniform over the working surface. It is unfortunate that we have only qualitative information on the thermal history of blank and finishing molds during various glass-making service. When actual thermal cycles in the mold are available for all of the permutations and combinations of glass making, it will be less difficult for the foundry to meet the specifications of the glass industry.

We wish to thank all those who took part in the discussion and thus made possible comparison of the data obtained with similar data obtained in other tests. The discussion also supports our thought as to the importance of determining the elastic modulus in our current research program and in service testing of the cast iron compositions which is currently being carried out.

Acid Electric Furnace Slag Control

By John Juppenlatz*, Lebanon, Pa.

Abstract

The author first discusses the recent developments made in slag control in the process of steel melting. Then he reviews some schemes to determine slag conditions, describing "viscosimeter" developed by Dr. Herty. Continuing, the author discusses slag sampling and gives details of the components of steel slags, showing the relationship of silica, iron oxide, manganese oxide and calcium oxide to each other. Effects of lime content are described and the reaction occurring in acid furnace slags. The volume of slag is given special attention. The author, in concluding the paper, advocates standardized procedure in melting practices with control of the slag through use of the viscosimeter.

1. The subject of slag control in the process of melting steel has, in the past few years, received considerable attention. A review of many recent papers[1] by Frank G. Norris covers the subject of slag control in basic open-hearth furnaces. Practically all of the published data concerns the basic practice, indicating the physical chemistry of the slag and steel making process. Information given in a paper by Herty[2] has been of great value to the basic producers of steel in controlling and maintaining definite types of slags in producing a stipulated grade of steel. More consistently uniform physical and metallurgical properties are possible by proper slag control. Great strides of progress are acknowledged by the basic producers of slag controlled steel[3].

2. Published data upon acid slag control is meager and quite limited. In 1939, the technical and operating executives group of

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1 Superior numbers refer to bibliography at the end of the paper.

Note: This paper was presented at a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

division No. 1 of the STEEL FOUNDERS SOCIETY OF AMERICA[4] undertook a study of slag control which covered both acid and basic electric and open hearth grades of steel for castings. Some progress was made in methods of slag control, particularly for acid steels. Many of the foundries have developed methods of acid slag testing and are continuing to profit by the experience so gained.

3. In the past, slag control at the furnace depended almost entirely upon the melter's judgment. His visual observations could hardly be stated in quantitative terms as having much value.

MANY SCHEMES TO DETERMINE SLAG CONDITIONS TRIED

4. Many schemes have been devised to determine slag conditions at various intervals of the heat of steel. Some of these tests involve color of fracture, pancake tests, appearance of stringers from rod and spoon tests, and inclined plates, as well as viscosity. Control tests by slag density methods warrant merit, since the slag density is related to its chemical composition. Quick density tests can be made at the furnace by weighing a known volume of slag and, by pre-determination, the chemical composition of the slag indicated. This method of slag control has become less popular due to the problem of obtaining a sample entirely free of gas voids and steel shot inclusions. Also the time involved in making the tests was often excessive.

5. The chemical composition of an acid slag is of prime importance as it is relative to the bath composition at a given time and temperature. These slag analyses are long and tedious, requiring too much time to be of any practical value to the melter, especially one operating a small electric furnace. Successful slag control methods for the acid electric furnace must be quick and informative to the operator as both slag and metal reactions are rapid.

SLAG VISCOSITY

6. Acid slag viscosity is relative to its chemical composition. Slag viscosities tests may be made and noted in comparable values. The time required for testing is short making it of immediate value to the melter.

7. The instrument for measuring the viscosity of slags, shown in Fig. 1, is called a "viscosimeter" which was developed by Dr. C. H. Herty, Jr.[5] Its design has been modified somewhat. It

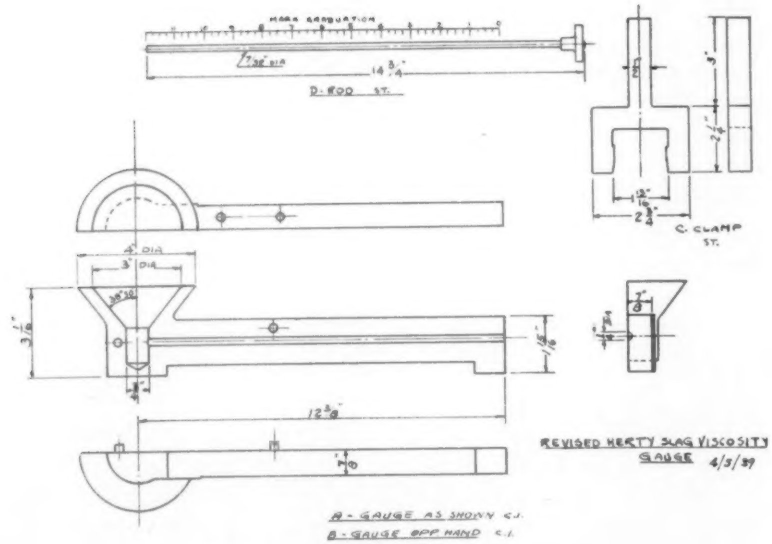

FIG. 1—REVISED HERTY SLAG VISCOSITY GAUGE.

consists primarily of a vertical receiving funnel with a horizontal hole, ¼-in. in diameter, in which the molten slag runs before chilling. An insert rod, calibrated in inches, can be immediately inserted and the amount of slag flow or viscosity noted. For example, a thick, heavy or viscous slag may flow and measure one-in.; while a fluid, watery slag may flow and measure 11-in. The viscosimeter values are considered one and 11-in., respectively, and later referred to as such.

SAMPLING SLAG

8. Sampling of the slag should be carefully performed, using a spoon that is clean and previously warmed up with a coating of slag. Samples should be taken between the electrodes or in their close proximity, quickly withdrawn and inverted into the funnel of the viscosimeter. This operation is important since the temperature of the slag affects its viscosity. To take a sample too close to the arc or near the door yields high or low values, respectively. Heavy top slags should be pushed aside, endeavoring to obtain a slag sample nearest the slag-metal interface. The viscosimeter may become warm enough so handling with gloves becomes necessary and does not materially affect the results.

COMPONENTS

9 The usual components of slags of acid electric steels as encountered by the writer consist of silica (SiO_2), iron oxide (FeO) and manganese oxide (MnO), with varying amounts of calcium oxide (CaO). The aluminum oxide (Al_2O_3) and magnesium oxides (MgO) are usually less than one per cent. Other components are only present in relatively small amounts and for this reason are neglected in further discussion. Silica (SiO_2) is considered an acid constituent and FeO, MnO and CaO as basic constituents. Total iron oxide, FeO plus Fe_2O_3, is expressed as FeO.

10. Many viscosity tests were taken from several heats. later making chemical analyses of the slags and correlating the data with the varying metallurgical results. The tests, as later discussed, were taken from one acid electric furnace melting an average heat of 3.3 tons of plain carbon steel. These viscosity tests have continued as routine for a period of three years and some of the data are given here.

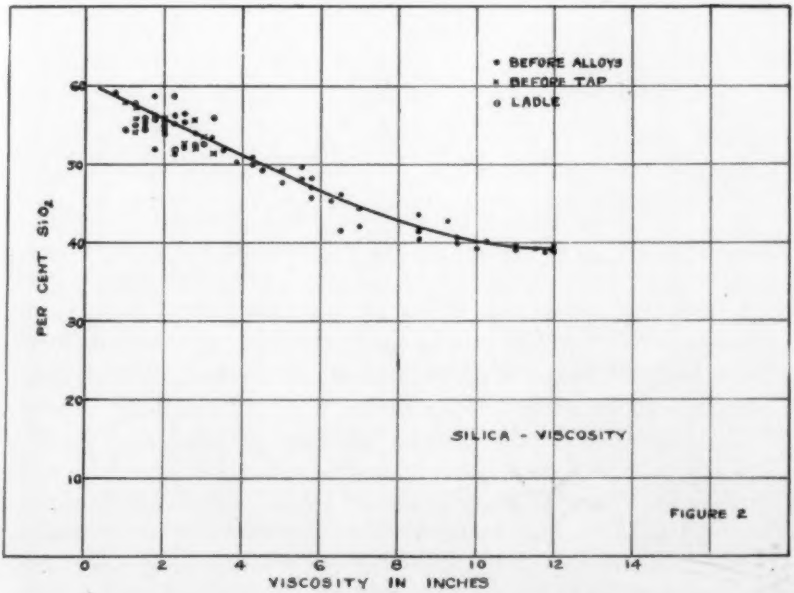

FIG. 2—RELATIONSHIP OF SILICA CONTENT AS PLOTTED AGAINST VISCOSITY VALUES.

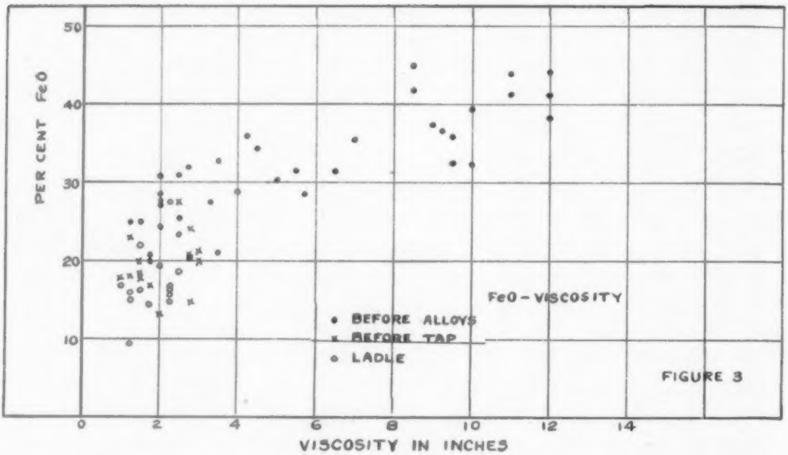

FIG. 3—RELATIONSHIP OF IRON OXIDE AS PLOTTED AGAINST VISCOSITY VALUES FOR THE SAME SLAGS AS SHOWN IN FIG. 2.

DISCUSSION OF CHARTS

11. Fig. 2 shows the relationship of the silica content as plotted against the viscosity values. These tests were taken at various intervals from the melt down period, through the tapping period and the final ladle slag after the heats were entirely poured from bottom pour ladles. A comparable curve may be plotted showing the viscosity-silica ratio. Fluidity or viscosity values are higher with low silica contents and lower with high silica contents, respectively.

12. Fig. 3 represents the same slags showing the relationship of iron oxide (FeO) as plotted against the viscosity values. There is a definite trend showing higher viscosity values with higher FeO contents. However, these points are scattered and to indicate an average curve that possesses value is difficult. If the other basic constituents MnO and CaO were constant, the FeO values would have indicated a more definite curve.

13. Fig. 4 shows the viscosity values of the same slags plotted against the manganese oxide (MnO) content. Again it is not possible to indicate an average curve. However, it should be noted that the MnO content varies at different intervals of the heats, showing an average of 12.7 per cent MnO before alloy additions, 16.6 per cent MnO after alloy additions and before tapping, with 18.6 per cent MnO after pouring the entire heat. This was due

to the replacement of FeO in the slag by the formation of MnO which will be discussed later.

14. Fig. 5 shows the lime (CaO) content of the same slags as plotted against the viscosity values. The CaO content varies from 0 to 10 per cent and does not, in these amounts, control its viscosity.

15. If the basic constituents were totaled, such as the FeO, plus MnO, plus any CaO present, an inverse curve of the SiO_2 would prevail as shown by Fig. 6. The viscosity curves of the acids and bases intersect at a 50 per cent value with a 4½-in. viscosity value. At this point the slag will have a greenish-black fracture. If the the MnO content should be above 20 per cent the color of the fracture will be more definitely green as encountered with a high manganese heat (1.0 per cent or over), with a correspondingly lower FeO content in the slag. Normally, even slags with CaO contents up to 10 per cent, a slag with 4½-in. viscosity value will be changing from a black to green by fracture.

16. The basic constituents may vary in individual percentages without appreciably changing the viscosity, as shown by the preceding viscosity curves of FeO, MnO and CaO. The total basic constituents are controlling factors of acid slag viscosity, or the acid constituents, namely, silica, control its viscosity.

17. With the basic components varying in percentages as shown, the silica viscosity curve (Fig. 2) seems to be most valuable to the melter as the controlling factor of slag viscosity.

18. If the slag contained silica and iron oxide as the main components, then the iron oxide would control the viscosity as well as silica. However, this example is contrary to normal slag operating

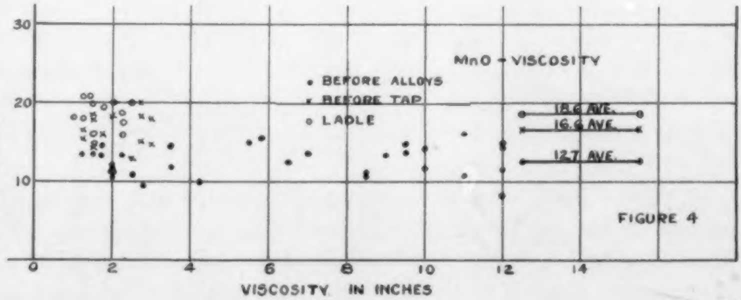

FIG. 4—VISCOSITY VALUES OF THE SLAG SHOWN IN FIG. 2 AS PLOTTED AGAINST THE MANGANESE OXIDE CONTENT.

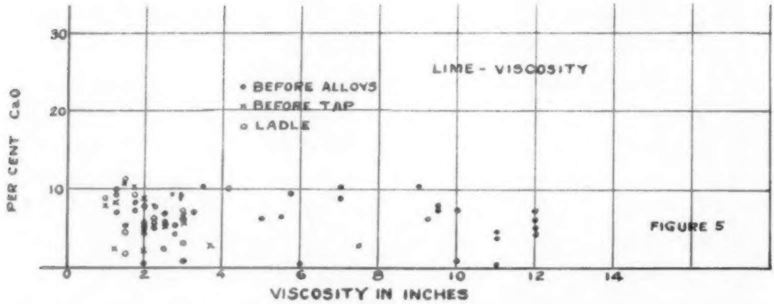

FIG. 5—LIME CONTENT OF SLAGS SHOWN IN FIG. 2 AS PLOTTED AGAINST THE VISCOSITY VALUES.

conditions since manganese oxide is present with varying amounts of lime.

LIME CONTENT EFFECTS

19. If a slag has 40 per cent SiO_2, the balance is obviously of basic constituents. With a lime content of 7 per cent, slags *A* and *B* are possible as given below:

	A Per Cent	*B* Per Cent
SiO_2	40.0	40.0
FeO	30.0	40.0
MnO	23.0	13.0
CaO	7.0	7.0

20. With constant SiO_2 values the FeO and MnO values vary. Slag *A* contains 30 per cent FeO and slag *B* 40 per cent FeO, the difference of 10 per cent being adjusted by the MnO content. Either slag *A* or *B* would have approximately the same viscosity value of 10-in. There is in each case approximately equal amounts of FeO available for bath reactions, the remainder being consumed for chemical balance.

21. Lime (CaO) functions as a basic constituent and is usually present in amounts from 0 to 12 per cent. Lime may be used in these amounts to replace FeO and MnO or to increase the basicity of the slag. The use of lime does not appreciably affect the silica-viscosity ratio, as this silica curve applies to lime-bearing or lime-free slags. Lime can be used advantageously to reduce the amounts

of FeO and MnO required for necessary chemical balance. It also permits the use of a lower FeO content of the slag throughout various stages of a heat, freeing and making available FeO for bath reactions that normally would be required for an equivalent amount of basicity.

22. If the FeO content of the slag is low before deoxidization, the recovery of manganese will be correspondingly higher. In this manner lime aids in the conservation of manganese when the proper SiO_2 content is maintained with a low FeO content.

REACTIONS

23. The acid furnace being made with a silica lining permits the reduction of silicon and in this manner is distinct from the basic process. Acid slag metal equilibrium conditions at various temperatures are of interest to the steelmaker but are not within the scope of plant investigation.

24. The acid electric furnace is accepted as a rapid melting medium, consequently the slag-metal reactions are of relatively short duration. The most probable reactions are discussed in logical sequence.

25. When melting is accomplished under slags containing free FeO or an excess required for composition balance, the reactions are as follows:

$$\text{Reaction (1)}\quad Mn + FeO \leftrightharpoons MnO + Fe$$
$$\text{Reaction (2)}\quad Si + 2FeO \leftrightharpoons SiO_2 + 2Fe$$

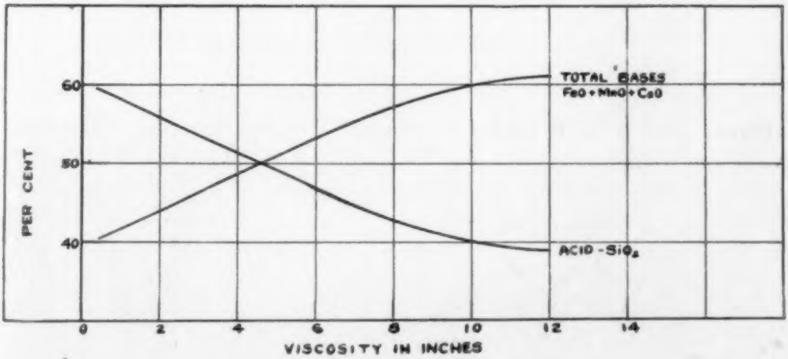

FIG. 6—IF BASIC CONSTITUENTS ARE TOTALLED, SUCH AS FEO, PLUS MNO, PLUS ANY CAO PRESENT, AN INVERSE CURVE OF THE SIO_2 WOULD PREVAIL AS SHOWN.

26. These reactions take place upon melting and continue in proportion to the amounts of available elements and compounds for reaction. Conditions of equilibria between slag and metal continue with increasing temperature. To effect these reactions a slag of 50 per cent SiO_2 or less seems essential with a viscosity of 4½-in. or more. The silicon content of the bath during melting seems to be of major importance. Silicon has the ability to absorb gases such as oxygen, hydrogen and nitrogen. By removing this silicon content of the bath to low levels, 0.05 Si and under, these gases are probably released with many suspended silica particles of minute nature.

27. When these reactions have practically terminated, the carbon reaction becomes prominent.

$$\text{Reaction (3)} \qquad C + FeO \leftrightharpoons CO + Fe$$

28. This reaction does not take place with vigor until the bath attains a high temperature. Rapid heat input hastens the "carbon-boil" into activity.

29. These three reactions are believed to continue as the bath increases in temperature and until the slag reverts from the basic to acid side. This dividing point may be considered reached when the slag has attained 50 per cent SiO_2 with a viscosity value of 4½-in. under such a slag. If the bath and slag have reached equilibrium, the FeO content of the bath and slag have become lowered to a point where little FeO is available for further active reaction.

30. Boiling may still continue under distinctly acid slags at the expense of carbon causing the following:

$$\text{Reaction (4)} \ SiO_2 + 2C \leftrightharpoons Si + 2CO.$$

In an active bath this reaction may visually appear as a "carbon-boil" but, in reality, it could be termed a "silicon-boil." The carbon acts upon the SiO_2 of the hearth and slag reducing silicon with the evolution of CO gas similar to that of the "carbon-boil." Rapid heat input hastens this reaction. It is destructive to the hearth and walls as they become softened by the high temperatures and are attacked by the carbon-silica reaction. This method of silicon reduction is often intentionally employed. Manganese may also be reduced when slag conditions permit and usually accompanies reaction (4) in a mild manner.

$$\text{Reaction (5)} \ MnO + C \leftrightharpoons Mn + CO$$

31. For this reaction, high temperatures are necessary, with slags high in SiO_2, low in FeO, without being deficient in MnO.

VOLUME OF SLAG

32. Volume of slag is another consideration of practical value. Large slag volumes cause sluggish reactions, since both slag and metal must reach equilibrium for each phase or reaction. Slag is not a producer of tonnage of finished steel and should be kept at minimum values even though it is an essential part of the process.

33. The following reaction takes place throughout the melting and finishing periods:

$$\text{Reaction (6)}\ Mn + SiO_2 \leftrightharpoons 2\,MnO + Si$$

The manganese may reduce silica from the lining or slag, particularly after the final additions of manganese when bath temperatures are high. This reaction accounts for the high silicon pick-up with heats of high manganese contents of 1.00 per cent or over. When the finishing slag is of low viscosity, abnormally high in SiO_2, the reduction of silicon is the greatest. When the slag is low in SiO_2 and high in FeO, the silicon reduction is not so apparent, but the manganese loss increases as in reaction (1).

CORROSIVE EFFECT

34. The corrosive effect of hearth and walls may be primarily attributed to:

$$\text{Reaction (7)}\ X\,MnO \underbrace{+\ SiO_2}_{\substack{\text{Slag or}\\ \text{solid}}} \leftrightharpoons \underbrace{(MnO)\ X - SiO_2}_{\substack{\text{(Liquid manganese}\\ \text{silicate)}}}$$

35. This reaction is a probable result of reactions (1) and (6), primarily causing increased slag volume especially apparent with high manganese heats. The reaction is most forceful when the bath and lining are at high temperatures. If the MnO content of the slag and bath become proportionately high, the attack on the hearth and walls becomes more severe, resulting in excessive increases of slag volume. The "X" as used in reaction (7) denotes the presence of MnO in amounts greater than those required for chemical balance of the slag.

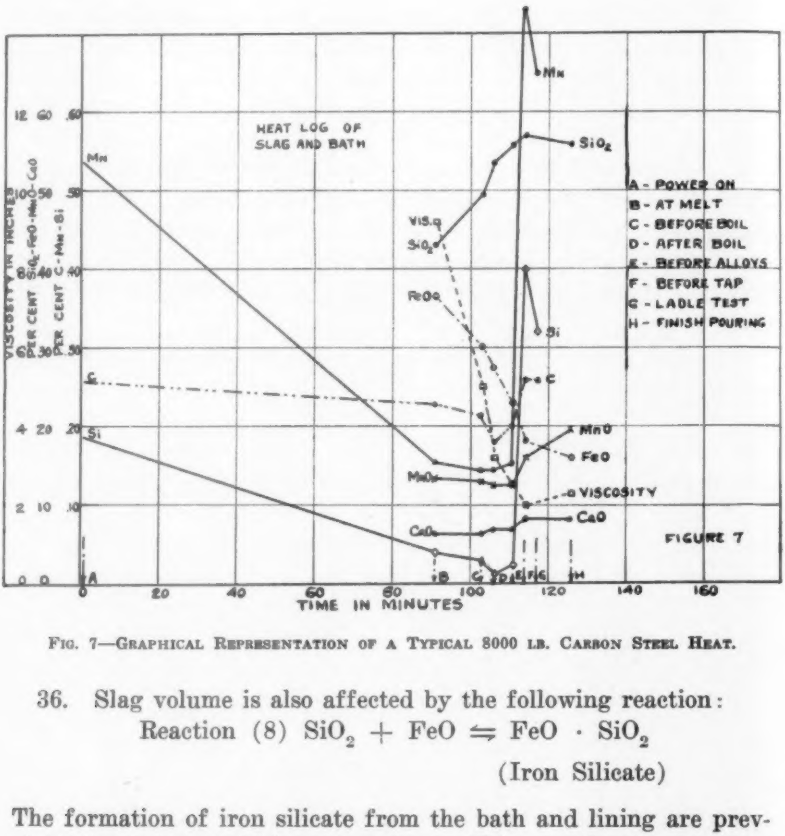

FIG. 7—GRAPHICAL REPRESENTATION OF A TYPICAL 8000 LB. CARBON STEEL HEAT.

36. Slag volume is also affected by the following reaction:

$$\text{Reaction (8)} \quad SiO_2 + FeO \rightleftharpoons FeO \cdot SiO_2$$

(Iron Silicate)

The formation of iron silicate from the bath and lining are prevalent throughout melting operations. This reaction is not considered too destructive on the lining when reasonably low FeO limits are maintained. When a slag is high in free available FeO and temperatures are high, increased slag volumes cannot be avoided.

SUMMARY

37. The reactions as outlined are the most probable for the acid electric furnace. In order to briefly summarize the preceding data, Fig. 7 gives a graphical representation of a typical 8000 lb. carbon steel heat.

38. The scrap charge consisted of approximately 45 per cent foundry returns, 20 per cent punchings, 27 per cent plate and 8 per cent rails. Melting was done with 125 volts on the open delta

and this continued to time "D" when the voltage was reduced to 90 volts on the open delta. At time "B" all the scrap was under the cover of slag and first tests of metal and slag were taken. The manganese content of the bath was greatly reduced during the melting period. The silicon was likewise reduced, but the loss of carbon was comparatively slow. During the period of "A" to "B" little boiling action occurs and reactions (1) and (2) take place. At time "B" a slag viscosity of 9¼-in. was noted, with 43 per cent SiO_2 and 36.5 per cent FeO. The slag was distinctly basic with a considerable excess of available FeO. More vigorous boiling action started at "B" and with increasing temperature the "carbon-boil" [Reaction (3)] continued in greater force from time "C" to "D." When this reaction was nearly completed the "silicon-boil" [Reaction (4)] became more effective, in periods "D" and "E," until the heat input had been reduced. At time "E" silicon and manganese alloy additions were made. Metal tests were taken at period "F" before tapping, "G" during pouring and "H" the final ladle slag.

39. The slag metal reactions as previously presented may be followed throughout the various stages of the heat. The loss in FeO content of the slag at time "E" has been practically replaced by increased MnO content. The time involved for this change, including that of the bath for equilibrium, was very short.

40. Final deoxidization was made with ¾ lb. of aluminum per ton in the ladle. Tensile values, chemical analyses and heat treatments of attached coupons are given below:

Heat Treatment		*Yield Point, lb. per sq. in.*	*Tensile Str., lb. per sq. in.*	*Elongation, per cent*	*Reduction of Area, per cent*
Annealed	1600	39500	71500	30.0	48.6
Normalized	1600				
Temper	1200	43000	73000	32.5	56.0

Analyses, per cent	C 0.26	Mn 0.70	Si 0.32	S 0.034	P 0.022	Cr 0.03
	Ni 0.05	Cu 0.17	Mo 0.02	V 0.01		

SLAG CONTROL

41. Slag control in the acid electric furnace is of major importance since the slag-metal reactions continue until equilibrium has been reached. With the viscosimeter as a working tool, it becomes easier to determine the condition of the slag, indicating the amounts

of ore, sand or lime needed for slag adjustment to obtain the proper slag-metal reactions. It supplies fast and indicative slag control tests essential to the small electric furnace due to the rapidity of reactions and their end-points.

42. No attempt has been made to stipulate set or definite slag values for operation, since it is realized that some furnaces are more adaptable to one practice than another. Variables in electric furnaces must be accepted, such as depth of bath, area of slag, volume of slag, power input and regulation, type of scrap, atmosphere, etc. In any case, a standardized procedure of melting practice in conjunction with the viscosimeter should prove advantageous.

ACKNOWLEDGMENT

The writer acknowledges permission granted by G. R. Casey, president, Treadwell Engineering Co., to publish this paper and constructive comments made by Dr. C. H. Herty, Jr., Bethlehem Steel Co.

Bibliography

1. Norris, Frank G., "*Some Open Hearth Problems in 1941*," METALS AND ALLOYS, (December, 1941), pp. 856-864.

2. Herty, C. H., Jr., "*The Deoxidation of Steel*," COOPERATIVE BULLETIN No. 69, Carnegie Institute of Technology and Mining and Metallurgical Advisory Boards.

3. Reagan, W. J., "*Open Hearth Slag Control*," IRON AGE, (August 17, 1939).

4. STEEL FOUNDRY FACTS, (May, 1941).

5. Herty, C. H., Jr., Christopher, C. F., and Freeman, H., "*The Physical Chemistry of Steel Making*," COOPERATIVE BULLETIN No. 68, Carnegie Institute of Technology and Mining and Metallurgical Advisory Boards, p. 27.

DISCUSSION

Presiding: C. E. SIMS, Battelle Memorial Institute, Columbus, O.

Co-Chairman: JOHN HOWE HALL, Philadelphia, Pa.

CHAIRMAN SIMS: I particularly like the presentation of this paper, and the form in which it is written. It is an approach to slag control. There is no air of finality in it, as if it were all cut-and-dried. This is one of the first, if not the first paper that has been presented before this Association on acid slag control, which is a comparatively new tool.

I have heard some discussion on slag control in which it seemed to be considered that the viscosity *per se* was of great value. It apparently did not make much difference how one controlled viscosity, just so one arrived at a certain figure, but it is plain to see that viscosity is controlled by three principal factors; the lime, iron oxide and manganese

oxide. Obviously, slag that has low viscosity, due to a large content of manganese oxide, will not be quite as active a slag, from the oxidizing standpoint, as a slag that has low viscosity due to a high iron oxide content.

MEMBER: Have you made any analysis of the Fe_2O_3 or Fe_3O_4 or just plain iron? We have found definitely that it is the Fe_2O_3 or Fe_3O_4 that changes the viscosity.

MR. JUPPENLATZ: We have determined the Fe_2O_3, but did not go to the extent of determining Fe_3O_4. All the iron oxide contents as presented were calculated as FeO. With a total of 25 per cent FeO, the Fe_2O_3 ran between 3 and 8 per cent. I have not studied the effects of the Fe_2O_3 or Fe_3O_4 on slag viscosity.

I believe that, if all iron oxide is added into the total basic constituents, this total controls the viscosity. It is really the controlling factor during melting. The acid constituents, silica plus any alumina, are obviously the remaining constituents. Alumina is usually present in small amounts. In the acid furnace, silica is reasonably constant. It is not the controlling factor, but it is one which we recognize and use in that fashion.

MR. JUPPENLATZ: We have made no mineralogical studies of these slags. Most of the slags are of the glassy nature and I believe it would be a very interesting study.

MEMBER: I would like to ask if the author will briefly enumerate some of the beneficial effects that he obtained from slag control as to viscosity of metal, etc.

MR. JUPPENLATZ: That is a rather broad question and I am not going to try to answer it as fully as I might like to. The viscosity of slag is relative to its chemical composition. Slag and metal tend to approach equilibrium at various times and temperatures. These things being true, we can obtain a great deal of benefit from them. If we have a constant slag volume and a constant chemical composition of a slag, we should have constant recoveries of manganese and silicon, and by doing that, our chemical analysis of the resulting steel should be within our specifications. That is one of the real benefits that almost anyone can derive.

As far as fluidity of the material is concerned, I would say that certain types of slag definitely have a bearing upon fluidity. That is another phase which I believe could be studied and would make a very interesting paper. I do not have the information in actual figures, but from practical observation, it does make quite a difference.

G. S. BALDWIN[1]: I would like to ask Mr. Juppenlatz whether or not he considers that the factor of fluidity is the only condition of measuring slag. We talk about chemical analysis of the slag, and the effects of FeO and Fe_2O_3 were brought up. Since the slag control is rather new, and since many of us do not have the facilities to analyze our slags, it is better, is it not, for the time being, to leave the window dressing out and use just a straight fluidity measurement and go on from there? That is, discussions of the effects of Fe_2O_3 and Fe_3O_4 on the fluidity are all right, but to really get started, all you need is a viscosimeter

1 Standard Steel Works Div., Baldwin Locomotive Works, Burnham, Pa.

and a lot of tests. Put those measurements down on the heat records, keep on doing it, and you will finally end up with a fund of information that can be correlated with effects noticed on the heat.

MR. JUPPENLATZ: Mr. Baldwin, you apparently have done work along the same lines that we first started on. We did not know anything about slag viscosity but we were willing to see if we could not do something about learning how to make good steel. We went at it rather blindly. We made a number of heats, say, a hundred. We took slag viscosities at various intervals of the heat. We did not pay much attention to them until we had a fund of information where we could plot chemical compositions and, we will say, manganese and silicon recoveries. We took some tests of the bath at the same time as the preliminary tests, and we took physical properties and the character of other tests. When we got that information, we had a trend of where we wanted to go and what kind of slags we wanted. From that point, we started to have a definite aim of slag viscosities. As a matter of fact, I would say that the melter on our furnace is not truly interested in chemical compositions of slag. All he is interested in is the final analysis of the heat. Neither is he interested in whether the slag measures 2, 4, 6 or 8-in. However, he does know that if he gets a slag measuring a certain length at a certain time in the heat, he should have certain results. In that way, he is out of trouble, and that is about all that the melter really cares about.

MEMBER: Have you found any correlation between specific gravity of slags and manganese recovery? You said that, if slags were constant, your manganese recovery was constant. Have you done any testing of specific gravity against manganese recovery?

MR. JUPPENLATZ: I have not done enough specific gravity work to answer that question.

E. C. TROY[2]: There is a definite relationship between the specific gravity and viscosimeter reading, either of which can be plotted against the total SiO_2 of the slag. The recovery of manganese is dependent on the percentage composition and total mass of the slag. Controlled recovery of manganese can be accomplished if the specific gravity or viscosimeter value is kept under control with a standard mass of slag. Control of mass cannot be easily accomplished and is the reason why manganese recovery cannot be completely controlled by fixed chemical compositions. Our company has changed from specific gravity to the viscosimeter because it is an easier and more certain tool to use.

MR. BALDWIN: Have you found any means of measuring slag volume?

MR. JUPPENLATZ: Slag volume by measurement is a difficult thing. I still believe that it is a matter of judgment. The means that we have used in controlling slag volume is to remove as much slag as we can from the furnace before the real boil occurs, so that we have sort of a constant. I do not believe that it makes much difference how much slag we have, as long as we can hold it at a constant. Therefore, with some method like that, I believe that you can maintain results from time to time. To measure the depth or volume of slag as a true indicator before a heat is tapped would be quite some problem.

[2] Dodge Steel Co., Philadelphia, Pa.